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SOCIETY OF ENGINEERS.

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SOCIETY OF ENGINEERS.

ESTABLISHED MAY, 1854.

TRANSACTIONS FOR 1866.

PLACE OF MEETING, LOWER HALL, EXETER HALL, STRAND.

OFFICES, No. 6, WESTMINSTER CHAMBERS, VICTORIA STREET, WESTMINSTER.

LONDON:
E. & F. N. SPON, 48, CHARING CROSS.
1867.

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LONDON
PRINTED BY C. WHITING, BEAUFORT HOUSE, STRAND.

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PREMIUMS FOR 1866.

At the Meeting of the Society on January 21st, 1867, Premiums of Books were awarded to:—

THOMAS CARGILL, for his Paper "On the Six-way Bridge, Place de l'Europe, Paris."

ARTHUR JACOB, for his Paper "On Reservoirs and Embankments."

CARL R. VON WESSELY, for his Paper "On Arched Roofs.'

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On Arched Roofs. By Carl R. von Wessely 36

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On Incrustation in Marine Boilers. By Peter Jensen . 117

On Single and Double Riveted Joints. By Thomas Baldwin 150

The Railway Bridge at La Place de l'Europe, Paris. By Thomas Cargill 191

On the Designing and Construction of Storage Reservoirs. By Arthur Jacob 225

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SOCIETY OF ENGINEERS.

ESTABLISHED MAY, 1854.

RULES

AND

LIST OF MEMBERS.

COUNCIL AND OFFICERS FOR 1867.

COUNCIL.

WILLIAM HENRY LE FEUVRE, President.

BALDWIN LATHAM, Vice-President.

WILLIAM ADAMS	CHARLES JULIAN LIGHT
JOHN AIRD, Jun.	WILLIAM MACGEORGE
FREDERICK Wm. BRYANT	VAUGHAN PENDRED
WILLIAM CLARKE	JOSEPH PHILLIPS
JAMES HENDRY	FREDERIC C. REYNOLDS

Members of Council, ex officio.

HENRY PALFREY STEPHENSON ...	1856 AND 1859	Past Presidents.
ROWLAND MASON ORDISH.....	1860	
EDWARD RILEY	1862	
ROBERT MONRO CHRISTIE.....	1858 AND 1863	
CHARLES LLEWELLYN LIGHT	1864	
WILLIAM THOMAS CARRINGTON...	1865	
ZERAH COLBURN.....	1866	

ALFRED WILLIAMS, Hon. Secretary and Treasurer.

PERRY FAIRFAX NURSEY, Auditor.

GEORGE WASHINGTON HARRIS, B.A., Secretary.

PLACE OF MEETING:

LOWER HALL, EXETER HALL, STRAND.

OFFICES:

6, WESTMINSTER CHAMBERS, VICTORIA STREET, S.W.

April, 1867.

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LONDON:
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SOCIETY OF ENGINEERS.

RULES AND BYE-LAWS.

Object of Society.

The Society of Engineers is established for the advancement of Engineering Science and Practice.

The Election of Members, &c.

Number of Classes.

1. The Society shall consist of three classes—Members, Associates, and Honorary Members.

Qualification of Members.

2. Members shall be Gentlemen who are or have been engaged professionally in Engineering pursuits, and shall be above twenty-five years of age.

Qualification of Associates.

3. Associates shall be Gentlemen of scientific attainments, or those whose pursuits constitute direct or collateral branches of Engineering.

Qualification, &c., of Honorary Members.

4. Honorary Members to be nominated by the Council, not to exceed twenty in number, who shall be Gentlemen of distinguished attainments.

Mode of Election.

5. Members and Associates to be elected by ballot; one-third black balls to exclude. The ballot to take place at the first Meeting in each month. No Candidate to be re-balloted for within twelve months.

How to be Proposed.

6. Candidates to be proposed by a Member or an Associate of the Society, and recommended by at least three others, on a proposal form, stating the Candidate's qualifications, or the works upon which he has been engaged, which is to be forwarded to the Honorary Secretary at least seven days before any Ordinary Meeting. Candidates to be announced at an Ordinary Meeting, and to be balloted for at the succeeding

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ballot. In the case of non-election, no mention is to be made thereof in the minutes, nor any notice given to the unsuccessful Candidate.

Expulsion of Members and Associates.

7. No Member or Associate to be expelled without the consent of at least three-fourths of the Members and Associates present, or by proxy, at a Special General Meeting, called for such purpose.

Visitors.

8. Members and Associates to have the privilege of issuing cards of invitation for two visitors at each Ordinary Meeting.

Rules for the Election and Proceedings of Council and Officers.

Mode of Election.

9. The Officers of the Society to be elected at the General Meeting in December, each year, by ballot. The year of office being from the 1st of January to the 31st of December.

The Founders.

The Founders of the Society, "R. M. Christie and H. P. Stephenson, Esqrs.," to be permanent Members of Council.

Number of Officers.

10. The Officers shall consist of a Council of twelve Members, the Founders, the Past Presidents of the Society, the Honorary Secretary and Treasurer, the Auditor, and the Secretary. The Past Presidents to be limited to six, to retire by seniority, but to be eligible for re-election on the Council. The Founders, the Past Presidents, and the Honorary Secretary and Treasurer, shall be *ex-officio* Members of the Council. No Member can be elected on the Council unless he is or has been *bonâ fide* engaged professionally in Engineering pursuits.

Election of Auditor.

11. A Member (not being one of the Council) to be elected as Auditor, who shall make his report at the first Ordinary Meeting in each year.

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Quorum. 12. Four Members to be a quorum; the President to have the casting vote.

Election of President. 13. The Council to elect their President and Vice-President by ballot.

Occupation of Chair at Meetings. 14. In the absence of the President at any Meeting, the Vice-President shall take the chair, or in his absence a Member of the Council.

Management of Funds. 15. The Council shall have the sole management of the funds, and the entire superintendence of the Society.

Selection of Subject for Discussion. 16. The Council shall select the subjects and papers to be read and discussed at the Ordinary Meetings. Members and Associates wishing to read a paper, or who wish to have a particular subject discussed, must notify the same to the Council. Authors to be entitled to fifty copies of their Papers upon the publication of the Papers in the Transactions of the Society.

Special Meeting of Council. 17. A Special Meeting of the Council shall be called on the requisition of three of its Members.

Retirement of Council. 18. The Council to retire each year, but to be eligible for re-election.

List of New Officers. 19. The Council resigning office shall prepare a list of proposed new Officers, which shall be sent to each Member and Associate with the notice of the Annual General Meeting, at least fourteen clear days before the date of such Meeting.

Members wishing to be elected on Council. 20. Any Member offering himself for election on the Council, must give in his name to the Council on or before the first Ordinary Meeting in November. The name of such Member shall be appended to the List proposed by the Council.

Election of Council. 21. Members and Associates who do not attend the General Meeting should forward the above-named List to the

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Honorary Secretary, with such alteration in the name, as they desire, which, with those from the Members and Associates present, shall be handed to two scrutineers appointed by the President of the Meetings who shall ascertain the number of votes obtained by each Member; and the President of the Meeting shall make known the result to the Meeting.

Equality of Votes.

22. In case two or more Members have the same number of votes, the election of such Members to be decided by lot.

Rejection of Balloting Lists.

23. The scrutineers to reject all balloting-lists not properly filled up.

Custody of Funds and Accounts.

24. The Honorary Secretary and Treasurer shall keep the funds and accounts of the Society, which shall be open for the inspection of any Member or Associate.

Vacancy in Council.

25. The Council to fill up any vacancy that may occur in the Council or Officers between the Annual General Meetings.

SUBSCRIPTIONS, &c.

Entrance Fees.

26. An entrance fee of two guineas to be paid by resident Members, or those residing within a radius of twenty miles of the General Post-Office; and an entrance fee of one guinea by Associates residing within the same radius. An entrance fee of one guinea and a half to be paid by non-resident Members, or those residing beyond the above radius; and an entrance fee of fifteen shillings by non-resident Associates. The entrance fees to be paid on election.

Annual Subscriptions.

27. The annual subscriptions to be paid by resident Members to be two guineas, and by resident Associates one guinea. The annual subscription to be paid by non-resident Members to be one guinea and a half, and by non-resident Associates fifteen shillings. These subscriptions are to be paid in advance; they are due on the 1st day of January in each year.

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Life Members.

28. Life Members shall pay two guineas entrance fee, and twenty guineas for life subscription. Members shall have the option of becoming Life Members by paying twenty guineas.

Foreign Members and Associates.

29. Members and Associates residing permanently out of the United Kingdom shall be called Foreign Members and Associates, and shall pay one guinea entrance fee, and one guinea annual subscription.

Members and Associates Joining.

30. Any Member or Associate joining the Society shall pay his entrance fee, and first year's subscription, previous to receiving the benefits of the Society, which shall be considered as paid only to the 31st of December ensuing.

Disqualification to Vote.

31. Members and Associates whose subscriptions are unpaid are not qualified to vote.

Subscriptions in Arrear.

32. Members or Associates whose subscriptions are in arrear for two years, to be struck off the register of the Society, but to be still liable for the amount due.

Meetings of the Society.

Ordinary Meetings.

33. The Ordinary Meetings shall be held on the third Monday in January, and the first and third Mondays in February, March, April, the first Monday in May, the first and third Mondays in October, November, and December, unless otherwise specially ordered by the Council. The Chair to be taken at ½ past 7 o'clock, p.m.

Special General Meeting.

34. A Special General Meeting of the Society shall be called on the requisition of eight of its Members, who shall send to the Council the resolutions to be proposed by them at such Meeting, and these resolutions shall be printed and sent to the Members and Associates fourteen clear days before the date of such Meeting.

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Management of Discussion.

35. The President of the Meeting to have the power of directing the manner of discussion.

General Meeting.

36. There shall be a General Meeting held within the first fortnight of December in each year, to elect the Officers of the Society for the ensuing year.

Voting by Proxy.

37. Members and Associates are entitled to vote by proxy, on properly stamped papers.

Notice of Meetings.

38. At the commencement of each Session a Card shall be sent to each Member, Associate, and Honorary Member, giving the dates of all Meetings to be held during the Session.

Order of Business.

39. The Honorary Secretary, or the Secretary, shall commence the proceedings of each Meeting by reading the Minutes of the one preceding, and the names of the Gentlemen proposed for election.

Premiums for Papers.

40. Premiums, not exceeding in value the sum of Twenty Pounds, may be given annually for the best Papers read during the year. The decision to be left to the Council, who are disqualified from receiving premiums.

Publication of Papers.

41. Members proposing to read a Paper, to forward a copy of the same, written in the third person, for examination by the Council, to the Honorary Secretary, who will arrange the day for reading the same. The Society to have the right of publishing the Paper.

Transactions.

42. Members and Associates are entitled to a copy of the Transactions of the Society on their publication, for the years for which they have paid their subscriptions.

Certificates.

43. Certificates to be given to Members and Associates after having been duly elected.

Alteration of Rules.

44. No alteration to be made in the above Rules and Bye-Laws without the sanction of a Special Meeting called for that purpose.

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LIST OF MEMBERS, &c.

OF

THE SOCIETY OF ENGINEERS,

APRIL, 1867.

PAST PRESIDENTS.

George William Allan	1857
Henry Palfrey Stephenson	1856 and 1859
Rowland Mason Ordish	1860
James C. Amos	1861
Edward Riley	1862
Robert Monro Christie	1858 and 1863
Charles Llewellyn Light	1864
William Thomas Carrington	1865
Zerah Colburn	1866

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HONORARY MEMBERS.

Elected.	NAME.	Address.
1867	JOHN COUCH ADAMS, M.A., D.C.L., F.R.S. ..... Lowndean Professor of Astronomy and Geometry, University of Cambridge.	The Observatory, Cambridge
1867	GEORGE BIDDELL AIRY, M.A., D.C.L., F.R.S. ..... Astronomer Royal.	The Royal Observatory, Greenwich, S.E.
1865	HENRY BESSEMER	Queen Street Place, Cannon Street, E.C..
1867	SIR DAVID BREWSTER, K.H., D.C.L., F.R.S. ..... Principal and Vice-Chancellor of the University of Edinburgh.	Edinburgh and Allerly, Roxburghshire
1865	WILLIAM FAIRBAIRN, LL.D., F.R.S., Mem. Inst. C.E.....	Manchester
1867	EUGENE FLACHAT ..... President de la Société des Ingénieurs Civils Française.	9, Rue Moncey, Paris
1867	F. GRASHOF ..... Director des Vereins Deutscher Ingenieure	Carlsruhe, Baden, Germany
1867	SIR JOHN FREDERICK WILLIAM HERSCHEL, Bart., K.H., D.C.L., F.R.S.....	Collingwood, near Hawkhurst, Kent
1867	ROBERT NAPIER, Mem. Inst. C.E.	West Shandon, Helensburgh, Dumbartonshire
1867	JOHN PENN, F.R.S., Mem. Inst. C.E.	The Cedars, Lee, Kent, S.E.
1865	JOHN PERCY, M.D., F.R.S., F.G.S. ..... Professor of Metallurgy in the Royal School of Mines.	Museum of Economic Geology, Jermyn Street, S.W.
1867	LYON PLAYFAIR, C.B., Ph. D., F.R.S. ..... Professor of Chemistry, University of Edinburgh.	14, Abercromby Place, Edinburgh
1867	WILLIAM POLE, F.R.S., Mem. Inst. C.E. ..... Professor of Civil Engineering in University College, London.	Athenæum Club, S.W.
1867	WILLIAM JOHN MACQUORN RANKINE, LL.D., F.R.S. ..... Professor of Civil Engineering and Mechanics, University of Glasgow.	59, St. Vincent Street, Glasgow
1867	JOSEPH WHITWORTH, LL.D., F.R.S., Mem. Inst. C. E.	The Firs, Fallowfield, near Manchester

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LIFE MEMBERS.

Elected.	NAME.	Address.
1860	ANDERSON, George	16, Adam Street, Adelphi
1864	BAILLIE, Robert	London Yard, Millwall
1864	BAILLIE, Jonathan Robert	London Yard, Millwall
1865	DIRCKS, Henry	48, Charing Cross, S.W.
1863	FERRAR, William G.	13, Cannon Row, S.W.
1865	GRAFTON, John	7, Bloomfield Crescent, Paddington
1860	HURST, John Thomas	War Office, 109, Victoria Street, S.W.
1863	HUTTON, Darnton.....	Breakwater Fort, Plymouth
1866	MACGEORGE, William ..... *Member of Council.*	1, Castle Court, Birchin Lane, E.C.
1862	OLRICK, Lewis	27, Leadenhall Street, E.C.
1856	ORMISTON, Thomas	Breakwater Battery Works, Laira, Plymouth
1864	OWENS, Samuel.....	Whitefriars Street, Fleet Street, E.C.
1859	PADDON, John Birch	Brighton and Hove Gas Works, Hove Town, near Brighton
1863	PAPENGOUTH, Oswald C.....	46, Russell Square, W.C.
1858	RUMBLE, Thomas W.	5, Westminster Chambers, Victoria Street, S.W.
1864	WESTWOOD, Joseph	London Yard, Millwall, E.
1864	WESTWOOD, Joseph, Jun.	London Yard, Millwall, E.
1865	YOUNG, Charles Denoon	118, Leadenhall Street

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MEMBERS.

Elected.	NAME.	Address.
1858	ABEL, Charles Denton.....	20, Southampton Buildings, Chancery Lane, W.C.
1867	ADAMS, John H.	11, Laura Terrace, Campbell Road, Bow
1864	ADAMS, Thomas	5, Duke Street, Adelphi, W.C.
1865	ADAMS, William .... *Member of Council.*	21, Carlisle Terrace, Bow
1855	AIRD, John, Jun. ..... *Member of Council.*	Belvidere Road, Lambeth, S.
1854	ALLAN, George William ..... *Past President.*	Hendon Lodge, Wandsworth
1865	ALLEN, Thomas T.	1, Bree Street, Stratford-upon-Avon
1866	ANGUS, Robert N.	North Staffordshire Railway, Stoke-upon-Trent
1859	ARLISS, Walter John	Gas Works, Bell Green, Lower Sydenham S.E.
1864	ARMSTRONG, Henry	43, Manchester Street, Argyle Square
1866	ARMYTAGE, James	Preston, Lancashire
1861	ASHTON, John Peter	Railway Bridge Works, Runcorn, Cheshire
1860	AYDON, E. H.	Adam Street, Adelphi, W.C.
1859	BALDRY, James D.	2, Queen Square Place, Westminster, S.W.
1866	BALDWIN, Thomas	Corn Market Buildings, Bury, Lancashire
1865	BARLOW, John Simeon.....	40, Cranbourne Street, Leicester Square
1860	BARNARD, Clement	35A, Great George Street, Westminster, S.W.
1860	BARNARD, Edward Brown	14, London Street, City, E.C.
1864	BARTHOLOMEW, Eugene G.....	1, Wrotham Road, Camden Town
1865	BATLEY, William	46, Torriano Avenue, Camden Town
1863	BAYES, Thomas William	11A, Myddleton Square, E.C.
1867	BAYLEE, Charles Sextus	11, Oakley Crescent, Chelsea

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Elected.	NAME.	Address.
1861	BAYLEY, John Clowes	5, Robert Street, Adelphi, W.C.
1866	BEAUMONT, Joseph	3, Westminster Chambers, Victoria St., S.W.
1860	BENBOW, Walter	32, Bankside, Southwark, S.E.
1866	BENSON, Martin	14, Hinde Street, Manchester Square
1866	BERNAYS, Joseph	18, Woburn Place, Russell Square
1866	BLACKBOURN, James	Fairfield House, Droylesdon, nr. Manchester
1862	BLACKETT, William	106, Southwark Bridge Road, S.E.
1862	BOWDLER, George.....	Tower House, Spalding
1861	BOYCE, Robert H.	War Office, 109, Victoria St., Westminster, S.W.
1859	BOYS, John	Contractor's Office, Lavenham, Suffolk
1863	BRAIN, William James.....	11, Swan Terrace, East Surrey Grove, Peckham
1858	BRAITHWAITE, Richard	Penn Fields, Wolverhampton
1863	BRASS, Robert	7, East India Avenue, Leadenhall Street
1860	BROAD, Robert	Horseley Works, Tipton, Staffordshire
1865	BROTHERS, Horatio	Equitable Gas Works, Pimlico
1862	BROWN, Andrew Betts.....	13, Cannon Street, City, E.C.
1859	BROWN, J. B.	18, Cannon Street, City, E.C.
1865	BROWNE, Thomas.....	6, John Street, Adelphi, W.C.
1861	BROWNE, William Herbert	City of London Gas Works, Dorset St., E.C.
1857	BROWNING, Charles Edward ...	3, Victoria Street, Westminster, S.W.
1859	BRYANT, Frederick William ... *Member of Council.*	Contractor's Office, Chatham Place, E.C.
1866	BUCHANAN, Alexander.....	Britannia Works, Derby

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Elected.	NAME.	Address.
1856	BURN, Charles	Little Fife House, 3, Middle Scotland Yard, S.W.
1866	CARGILL, Thomas	Prospect House, Larkhall Lane, Clapham
1866	CARE, Robert	Engineer's Office, St. Katharine's Dock
1859	CARRICK, J.	9, Adam Street, Adelphi, W.C.
1858	CARRINGTON, William Thomas . *Past President.*	118, Leadenhall Street, E.C.
1867	CARRUTHERS, John H.....	3, Newman's Court, Cornhill, E.C.
1866	CARTER, R. W.....	61, Woodville Terr., Everton, nr. Liverpool
1866	CATHELLS, Edmund Small	Gas Works, Bell Green, Sydenham
1867	CHADWICK, Frederick	5, Westminster Chambers, S.W.
1867	CHAPLIN, Alexander.....	24, Cheyne Walk, Chelsea
1866	CHAPMAN, Parkinson	Pont-y-Pool
1854	CHRISTIE, Robert Monro ..... *Past President.*	64, Bankside, Southwark, S.E.
1867	CHURCH, Jabez.....	Hamlet House, Chelmsford
1864	CLARKE, Francis William	107, Camberwell Grove, S.
1866	CLARKE, William ..... *Member of Council.*	22, Great George Street, S. W.
1864	COLBURN, Zerah ..... *Past President.*	7, Gloucester Road, Regent's Park, N.W.
1865	COLSON, Charles	6, Landport Terrace, Southsea
1859	COLYER, Frederick	St. Mary's Iron Works, 6, Leman Street, Whitechapel, E.
1864	COOK, Robert J.	29, Charing Cross, S.W.
1862	COOPER, Edmund.....	4, Haddington Villas, Ilford Road, Stratford, E.
1855	COPLAND, Charles.....	British Provincial Gas Works, Hull
1866	COPLAND, Henry S.	5, Old Burlington Street, W.C.

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Elected.	NAME.	Address.
1865	COPLAND, Theodore O.	17, Burton Road, North Brixton
1867	CORNES, Cornelius	8, Emerson Street, Southwark
1861	COULTHARD, Hiram Craven.....	Park Iron Works, Blackburn
1866	COWAN, William	Kittybrewster Station. Aberdeen
1858	COWEN, John A.	Blaydon Burn, Newcastle-on-Tyne
1865	COX, Samuel H. F.	3, East Parade, Sheffield
1866	CRAVEN, William	9, John Street, Adelphi, W.C.
1865	CRUTCHLEY, William	Cliffe Terrace, Wakefield
1859	CUBITT, Charles	3, Great George Street, Westminster, S.W.
1867	DALE, Thomas	6, Queen's Terrace, Old Ford Road
1864	DANCHELL, F. Hahn	Horwich, near Bolton, Lancashire
1859	DAVENPORT, John Gladstone ...	8, Great Queen Street, Westminster, S.W.
1865	DAVIES, Hugh	39, Hope Street, Wrexham
1862	DAVIS, Henry D.	32, Moorgate Street, E.C.
1865	DAY, John.....	Perth
1867	DIXON, Adam	11, Adam Street, Adelphi
1859	DONKIN, Bryan.....	17, Argyll Road, Kensington, W
1865	DOUGLAS, Robert	Phœnix Gas Works, Vauxhall
1865	DOUGLAS, John	Flathouse, Portsea
1859	DYSON, Robert	Phœnix Works, Rotherham
1865	EASSIE, William	18, Great George Street, Westminster

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Elected.	NAME.	Address.
1860	EATON, James Allan.....	20, South Villas, Wandsworth Road
1858	ELLIOTT, James..... ..	New River Office, E.C.
1865	ENDES, Max Am.....	18, Great George Street, S.W.
1864	ESSON, William....	Ness House, Cheltenham
1867	ETLINGER, Ernest.....	69, Millbank Street, Westminster
1863	FARMER, John	18, Cambridge Road, Kilburn, W.
1860	FARRAND, Charles.....	Gas Works, Croydon
1863	FARRAR, Thomas S.	69, Millbank Street, Westminster
1858	FEATHERSTONHAUGH, J. F. W...	4, Richmond Villas, Westbourne Grove, Bayswater, W.
1861	FIELD, Edward.....	22, Buckingham Street, Adelphi, W.C.
1865	FIELD-MEAGHER, James	18, Great George Street, S.W.
1864	FILLARY, Thomas Foice	12, Amwell Street, Claremont Square, E.C.
1864	FIRTH, Edward.....	Hope Terrace, Thornhill, Masbro'
1865	FISHER, Henry Augustus	Rose Street, Plumstead
1863	FISHER, Joseph.....	17, Great George Street, Westminster, S.W.
1864	FISHER, Rowland.....	17, Great George Street, Westminster, S.W.
1866	FORD, Stephen	Saffron Walden
1865	FRANCK, James.....	Chenies Iron Works, Rickmansworth, Herts
1867	GIELGUD, Henry	3, George Yard, Lombard Street
1867	GILBERT, Francis S.	11, Park Street, Westminster
1862	GJERS, John	Tees-side Iron Works, Middlesborough-on-Tees

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Elected	NAME.	Address.
1859	GLYNN, John	31, Lavender Grove, Dalston
1854	GRAY, John William	Birmingham Waterworks, Birmingham
1863	GREEN, James B.	Salisbury Street, Blandford, Dorset
1861	GROVE, Thomas	76, Grosvenor Terrace, Pimlico, S.W.
1867	HACK, William	West Middlesex Water Works, Hampton
1865	HAKEWELL, H.	45, Crowndale Road, Camden Town
1860	HALL, George	Belvidere Road, Lambeth, S.
1865	HALL, Henry	Great George's Road, Waterloo, near Liverpool
1866	HANDYSIDE, Andrew	Britannia Works, Derby
1860	HARRIS, Robert	Gas Works, Bow Common
1864	HARTLEY, F. W.	55, Millbank Street, Westminster, S.W.
1861	HAWKES, George P.	12, Clerkenwell Close, E.C.
1867	HAY, Thomas J.	19, Great College Street, S.W.
1863	HAYWARD, Charles Marriott	
1862	HEAD, Charles Arthur	Teesdale Iron Works, Stockton-on-Tees
1861	HEAD, Howard	Teesdale Iron Works, Stockton-on-Tees
1858	HENDRY, James *Member of Council.*	8, Great George Street, Westminster, S.W.
1864	HENDRY, William	73, Queen Street, Cheapside, E.C.
1865	HEPWORTH, James	Hyde, Manchester
1860	HOBBS, Joseph Stephen	
1866	HOGARTH, Henry	9, Adam Street, Adelphi

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Elected.	NAME.	Address.
1862	HOLBROOK, Thomas H.....	Manor Iron Works, Manor Street, Chelsea, S.W.
1862	HOLLAND, John Henry.....	19, Buckingham Street, W.C.
1867	HORNER, John Jasper	30, Avenue Road, Hammersmith
1864	HORNIBROOK, John H. C. B. ...	Surveyor's Office, Redhill
1859	HORSLEY, Charles.....	3, Beresford Terrace, Highbury New Park, N.
1865	HOSKINGS, Henry.....	Hayle, Cornwall
1865	HOSKINGS, Oliver	Hayle Foundry Wharf, Nine Elms
1863	HOUGHTON, Francis Evelyn.....	Pumping Station, Crossness
1867	HOWELL, Joseph B.	3, West Bank, Sheffield
1861	HOWSON, Richard	Newport Iron Works, Middlesbro'-on-Tees
1859	HUMPHREYS, Joshua.....	2, Commercial Street, Middlesbro'-on-Tees
1862	HUNT, Henry W.	26, Parliament Street, S.W.
1859	HUTCHESON, Joseph.....	23, Queen's Road East, Chelsea
1860	HYAM, F. M.....	109, Westbourne Terrace, W.
1859	INGHAM, Frederick	Wortley, near Leeds, Yorkshire
1865	INGRAM, J. Jones...	Stuckton Iron Works, Fordingbridge
1858	IVESON, Thomas G.	43, St. Peter's Road, Mile End, N.E.
1867	JACOB, Arthur	Town Hall, Croydon
1866	JACOB, Augustus H.....	Inglis Road, Addiscombe
1862	JAMES, Christopher	Mountain Ash, Glamorganshire
1862	JENSEN, Peter	4, Gordon Grove, Holland Road, Brixton, S.

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Elected.	NAME.	Address.
1867	JOHNSTON, Robert E.	Railway Engineer's Office, Shrewsbury
1860	JOHNSTONE, George	Milton House, The Hamlet, Southend
1858	JONES, Alfred R.	24, Budge Row, City, E.C.
1862	JONES, Edward	The Larches, Handsworth, near Birmingham
1864	JONES, Thomas Dillon	18, Leadenhall Street, City, E.C.
1855	KEITH, John	Eltham, Kent, S.E.
1861	KELL, C. F.	8, Castle Street, Holborn, E.C.
1859	KERSHAW, B. D.	New River Office, Clerkenwell, E.C.
1864	KING, George	142, High Holborn, W.C.
1854	KING, Robert	Eltham, Kent, S.E.
1862	KIRKWOOD, Robert	Trinity, Edinburgh
1860	KOCHS, William Edward	29, Charing Cross
1859	LAING, Robert	Independent Gas Works, Haggerstone, N.E.
1867	LARGE, Thomas W.	Chandos Chambers, Buckingham St., Strand
1865	LATHAM, Albert	Town Hall, Croydon
1861	LATHAM, Baldwin..... *Vice-President.*	Town Hall, Croydon
1858	LE FEUVRE, William Henry ... *President.*	18, Great George St., Westminster, S.W.
1858	LEONARD, Edward J.	Engineer's Office, West India Dock
1856	LIGHT, Charles Julian..... *Member of Council.*	17, Great George Street, Westminster, S.W.
1859	LIGHT, Charles Llewellyn ..... *Past President.*	9, Adam Street, Adelphi, W.C.
1860	LITTLEWOOD, F.	

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Elected.	NAME.	Address.
1859	LOCKWOOD, Joseph	22, Kensington Park Terrace North, Notting Hill
1861	LONGBOTHAM, Abram	3, Hammersmith Terrace, Hammersmith, W.
1867	LOUCH, Arthur	The Elms, Lower Clapton
1862	LUCAS, John	Eighton Banks, Gateshead-on-Tyne
1865	LUND, James.....	10, Montague Terrace, Sheerness
1865	LUNDH, Svarrer H. H. O.	9B, New Broad Street, E.C.
1865	LYNCH, William	233, Portland Terrace, New Kent Road
1867	LYTTLE, William A.	5, Priam Place, Hammersmith, W.
1862	McCLEARY, James	Metropolitan Board of Works, Spring Gardens, S.W.
1867	McCOLLEY, Henry	8, Albion Terrace, King's Road, Chelsea
1865	McDOUGAL, J.	8, Dundas Terrace, Woolwich
1863	MANWARING, Joseph	78, Lombard Street, E.C.
1861	MARSHALL, B. W.....	9, Sumner Street, Southwark, S.E.
1863	MARTIN, Henry.....	Hanwell, Middlesex
1860	MARTINEZ, Manuel Garcia	4, High Street, Kensington
1867	MATHESON, Ewing	32, Walbrook, E.C.
1865	MAW, William H.....	37, Bedford Street, W.C.
1865	MAYO, Alfred	Weston-super-Mare
1866	MERRYWEATHER, Richard	Long Acre
1865	METHVEN, John	
1865	MILLER, Daniel.....	Normandy St. Alton, Hants
1858	MOORE, Edward H.	66, St. George's Road, Pimlico

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Elected.	NAME.	Address.
1859	MOORE, John Wilson	8, New Street, Spring Gardens, S.W.
1861	MORGAN, James T.	Messrs. J. Aird & Sons, Belvedere Road, Lambeth
1860	MORRIS, Frank	Gas Works, Brentford
1859	MORRIS, William	Kent Water Works, Mill Lane, Deptford
1859	MURIEL, George	Peak Hill, Sydenham
1867	NAYLOR, William	3, New Broad Street, E.C.
1863	NEWMAN, Frederick.....	Eldon Cottage, Long Ashton, Somerset
1862	NURSEY, Douglas Shafto	
1858	NURSEY, Perry Fairfax ..... *Auditor.*	166, Fleet Street, E.C.
1860	OHREN, John H.	Gas Works, Longton, Staffordshire
1856	OHREN, Magnus	Gas Works, Bell Green, Lower Sydenham
1861	OLANDER, Edmund	15, Parliament Street, Westminster
1860	ONSLOW, Douglas Arthur	
1857	ORDISH, Rowland Mason..... *Past President.*	18, Great George Street, Westminster, S.W.
1859	PAGE, George Gordon	16, Abingdon Street, S.W.
1862	PARKES, Matthew.....	Trinity Street, Hanley
1865	PATERSON, James	St. Leonard's Iron Works, Perth
1865	PEAK, Henry.....	4, Commercial Road, Guildford
1864	PENDRED, Vaughan ..... *Member of Council.*	163, Strand, W.C.
1863	PENRICE, Thomas.....	Thurlow Place, Wandsworth Road, S.
1866	PHILLIPS, Joseph .. .. *Member of Council.*	1, Westminster Chambers, Victoria Street, S.W.
1865	PICKERING, William.....	14, Chatham Place, Blackfriars

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Elected.	NAME.	Address.
1866	PINCHBECK, John	27, Leadenhall Street, E.C.
1862	PORTER, J. T. B.	7, John Street, Adelphi, W.C.
1864	PORTER, William	3, Manor Park, Lee, S.E.
1859	POTTS, B. L. F.	35A, Great George Street, Westminster, S.W.
1859	POTTS, J. T.	4, Oxford Villas, Fullwood Road, Sheffield
1862	PURVIS, William	Gas Works, Croydon
1856	QUICK, Joseph, Jun.	Sumner Street, Southwark, S.E.
1859	RAIT, George	Kingsland Road, N.E.
1865	RANKIN, John	Union Foundry, Liverpool
1865	READ, William	Wood Street, Swindon, Wilts
1864	READE, Sydney A.	Cherry Orchard Road, Croydon, S.
1862	REYNOLDS, Edward	Messrs. Naylor, Vickers, & Co., Sheffield
1866	REYNOLDS, Edwin J.	Newnham, Gloucestershire
1859	REYNOLDS, Frederic C. *Member of Council.*	35A, Great George Street, Westminster, S.W.
1860	RILEY, Edward *Past President.*	4, Park Place, Leeds
1863	ROBERTS, William	Millwall, Poplar
1866	ROBERTSON, George	Eccleston Iron Works, Pimlico
1860	ROBINSON, Charles	5, Barge Yard, Bucklersbury, E.C.
1867	ROOKE, Joshua	18, London Street, E.C.
1863	ROWELL, William F.	Coombe Hill Villa, Clevedon
1866	ROWELL, Haines	13, Mount Eliot Terrace, High Road, Lee, S.E.

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Elected.	NAME.	Address.
1859	RUMBLE, Robert A.	Metropolitan Board of Works, Spring Gardens, S.W.
1867	RUMMENS, Francis	5, Queen Square, Westminster
1862	SCHMITHENNER, L. S.	Regent's Canal Iron Works, Wharf Road, City Road, E.C.
1866	SCHONHEYDER, William	10, Claremont Terrace, Fentiman's Road, S.
1866	SCOTT, Walter	22, Park Terrace, Duffield Road, Derby
1866	SHEPPARD, Robert	13, Albion Terrace, Horsham
1865	SHUFFLEBOTHAM, Joseph W. ...	Appleton-in-Widnes, near Warrington
1865	SIMPSON, Thomas	South Stockton-on-Tees
1863	SKWARCOW, Peter.....	24, Leadenhall Street, E.C.
1865	SMITH, Frederick	Town Hall, Blackburn
1865	SMITH, John	27, Leadenhall Street, E.C.
1862	SMYTH, Samuel R.....	Dover
1862	SOMERVILLE, John	Gas Works, Maidstone
1865	SPENCER, Samuel	24, Great George Street, Westminster, S.W.
1859	STEPHENSON, Alexander Erskine	The Lindens, Nightingale Lane, Clapham Common, S.
1854	STEPHENSON, Henry Palfrey .... *Past President.*	25, Poultry, E.C.
1857	STEPHENSON, William Haswell	Throckley, Newcastle-on-Tyne
1863	STEVENSON, George Wilson... ..	14, Park Street, Westminster, S.W.
1864	STIDOLPH, Edward S.	5, Egerton Road, Blackheath Road, S.E.
1863	STRACHAN, John	68, King's Road, Reading
1866	STRANGE, Thomas.....	Broomfield Villa, Mold, North Wales

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Elected	NAME.	Address.
1861	SUGG, William	Vincent Street, Westminster, S.W.
1867	SUTHERLAND, D. D.	Hazelmere Cottage, Park Road, New Wandsworth
1859	SUTHERLAND, W. P.	13, Louvaine Road, Clapham Junction, S.W.
1862	SWAN, Edgar	13, Dorset Terrace, Clapham Road, S.
1861	SWAN, Lewin	
1862	SWAN, Thomas H.	59, Nelson Square, Blackfriars Road
1866	TAYLOR, W. Brounger	Church Street, Roussey, Hampshire
1861	THOMAS, William Henry	15, Parliament Street, Westminster, S.W.
1860	THORN, Alexander	Grosvenor Road, Pimlico, S.W.
1860	THORN, Peter	Ranelagh Road, Thames Bank, S.W.
1867	THORNELOE, George	190, Strand
1863	VEREY, Arthur	St. Margaret's, Herts
1867	WALKER, John	Middlesex County Asylum, Colney Hatch
1862	WALKER, John R.	Grove Boiler Works, Southwark, S.E.
1862	WALKER, William T.	Midland Works, Doddington, Shropshire
1858	WALLER, George	John's Place, Holland Street, Southwark, S.E.
1863	WALLIS, George A.	Water Works, Eastbourne, Sussex
1861	WALTON, Adolphus E.	6, Abchurch Yard, E.C.
1867	WARING, William	39, Prince's Gardens, Hyde Park
1862	WARREN, Alfred	189, Adelaide Road, N.W.
1862	WATKINS, Francis	London Works, Birmingham

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Elected.	NAME.	Address.
1860	WATSON, David	London Gas Works, Vauxhall, S.
1861	WATSON, Sydney	Contractor's Office, Lavenham
1864	WEBSTER, William	Wyburton Villa, Lee Lane, Blackheath, S.E.
1862	WELLS, George	12, North Street, Westminster, S.W.
1864	WESSELY, Carl R. von	18, Great George Street, Westminster, S.W.
1859	WHITAKER, Edmund J.	The Cottage, Nuttall, Nottingham
1865	WHITAKER, F.	3, Westminster Chambers, Victoria Street
1865	WHITEHEAD, Claude L.	Atherton, Chowbent, near Manchester
1855	WILLIAMS, Alfred *Hon. Secretary and Treasurer.*	64, Bankside, Southwark, S.E.
1860	WILSON, Alexander F.	Cyclops Works, Sheffield
1860	WILSON, Charles George	
1862	WILSON, George	Gas Works, Hove
1858	WISE, Francis	Chandos Chambers, Buckingham Street, Adelphi, W.C.
1867	WOOD, John	Church Street, Nuneaton
1863	WOOD, W. H.	The Lodge, West Hetton, Ferry Hill, Durham
1858	WOODHEAD, Edward J.	Denbigh Street, Pimlico, S.W.
1863	WOODHOUSE, John Thomas	Overseal, near Ashby-de-la-Zouch
1862	WORSSAM, S. W., Jun.	King's Road, Chelsea, S.W.
1865	WYLIE, A. C.	15, Cannon Street West, E.C.
1861	YARROW, A. F.	The Jerusalem, Cornhill
1859	YOUNG, Charles F. T.	7, Duke Street, Adelphi, W.C.
1859	YOUNG, Lambton J. H.	3, Priory Grove, Boltons, West Brompton

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FOREIGN MEMBERS.

Elected.	NAME.	Address.
1865	ADDIS, William J.	7, Church Gate Street, Fort, Bombay
1856	AIRD, A.....	Copenhagen
1865	BEELENKAMP, Charles W.	Cyclops Iron Works, Amsterdam
1864	BLYTHE, John Bennington	24, Cours de Jardin Public, Bordeaux
1862	BRANDON, David Hunter.....	13, Rue Gaillon, Paris
1867	FFINCH, Harry Maule	Colombo, Ceylon
1859	GORDON, George	India
1863	KIMBER, James	East India Irrigation Company, Midnapore, Bengal Presidency
1867	MAGNUS, David	Eutritzsch, near Leipzig, Saxony
1861	NETHERSOLE, George B.	India
1863	NETHERSOLE, William	India; Agents, Messrs. J. Elin and Co., 7, Bishopsgate Street, E.C.
1865	PARK, John C.	20, Via Carlo Alberto, Genoa
1861	SANDERSON, Charles.....	Bombay
1865	SCORGIE, James	23, Albion Place, Bombay
1865	SIMON, Alfred	6, Rue des Carmes, Paris
1867	SKWARCOW, John	Hotel de la Ville, Florence
1864	WANNIECK, Frederick	Prussia
1862	WELLS, Edward J.	Gas Works, Singapore
1863	WIGHTMAN, Arthur	Egypt
186[illegible]	WILSON, Alfred F.	Para Gas Works, Para

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ASSOCIATES.

Elected.	NAME.	Address.
1863	ADENBROOKE, Edwin	25, Poultry, E.C.
1867	ALLCOCK, Thomas	Bromley, Kent
1867	BAINBRIGGE, William A.....	2, Cloisters, Temple
1866	BARD, Alfred.....	Town Hall, Croydon
1864	BLACKBOURN, John	Regent's Canal Co., Macclesfield Street, City Road
1867	BRICKWELL, Francis.....	11, Grenville Street, Brunswick Square
1867	BUNN, Lockington D.	Holywell, Flintshire, North Wales
1867	CARNSEW, Henry	41, Parliament Street, Westminster
1867	CASH, Joseph	Gas Works, Hove, near Brighton
1864	CLARKE, Henry.....	Imperial Gas Works, Hackney Road
1867	COLES, Henry James	258, Marylebone Road, N.W.
1865	DAVEY, Henry	
1867	DAVIDSON, J. Y.	5, Brunswick Place, Lewisham Road
1864	DOCWRA, Harry.....	Mildmay House, Ball's Pond Road
1865	ERHARDT, Louis H. G.	
1867	FEATHERSTONHAUGH, William...	Town Hall, Redhill
1865	FISH, Walter Thomas	4, Jude Street, Bethnal Green
1867	FLAVEL, Sidney.....	Horsley Works, Tipton, Staffordshire
1863	FLOWER, Adolphe A.	70, Albert Street, Regent's Park, N.W.
1867	FOREMAN, Robert S.....	Woodside, Elmstead, Chislehurst
1867	GRANT, Robert C.....	11, Victoria Road, Kensington
1865	GRAVELEY, George	29, Alfred Street, Bow

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Elected	NAME.	Address.
1867	HALD, J. D. F.	9B, New Broad Street, E.C.
1864	HALL, George Frederick	9, York Road, Queen's Road, Peckham, S.E.
1867	HARRIS, George W.	142, Adelaide Road, N.W.
1867	HATHERLEY, John R.	18, Great George Street
1866	HENRY, Michael	68, Fleet Street, E.C.
1863	HINTON, John Archibald	18, Great George Street, Westminster, S.W.
1864	HODGES, Frederick	Church Street, Lambeth
1867	HOLMES, John	25, Poultry, City, E.C.
1867	HOLMES, Thomas Knox	18, Abingdon Street, Westminster
1860	HOPE, Frederick	25, Poultry, City, E.C.
1867	HULBURD, Thomas	17, Silver Street, Falcon Square
1865	HUNTER, William	6, Anglesea Street, Cork
1867	JACQUES, Richard	Campanile Cottage, Canonbury Road
1862	JAMES, Samuel Hubbard	7, Dalston Place, Dalston, N.E., and Railway Works, Delhi, India
1863	LILLY, Alfred J.	Castle Street, Bridgewater, Somerset
1862	LIMBERT, John A.	9, Milton Place, Gravesend
1866	LIVESEY, Frank	Dulwich Common
1862	LUCAS, William H.	9, Belgrave Street South, S.W.
1867	MACLURE, Andrew	17B, Great George Street
1867	MATRAVERS, Henry	9, Dowgate Hill, E.C.
1867	MANLEY, Mark	8, St. George's Road, Regent's Park
1867	MAYHEW, George J.	30, Great George Street, S.W.

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Elected.	NAME.	Address.
1865	MEREDITH, William H.	9, Oakley Street, King's Road, W.C.
1863	MILLER, Henry.....	City Gas Works, Dorset Street, E.C.
1856	MORRISON, William Thomas ...	Montague Place, Clapham Road
1867	NIGHTINGALE, John S.....	19, Trigon Road, Clapham Road
1865	NUNN, A. R.	9, Great Percy Street, Pentonville, W.C.
1865	OATES, Eugene W.	72, Park Walk, Chelsea, S.W.
1867	OXFORD, William	41, Corporation Street, Manchester
1867	PARRY, Edward	29, Union Square
1865	REEVE, Thomas D.	Hawley Street, Margate
1867	REES, John Charles	6, Parliament Street, S.W.
1863	ROBERTS, Edgar Hewett	18, Great George Street, Westminster, S.W.
1866	ST. CROIX, Francis d'Auvergne de	Midland Railway Engineer's Office, St. Alban's
1867	SMITH, William.....	13, Northumberland Street, Strand
1867	TILL, Elliott Downs	26, Lombard Street
1867	USILL, George W.	9, Dorset Place North, Clapham Road
1865	VALLANCE, Frederick B.	5, Hanover Terrace, Regent's Park
1867	WADDELL, James	10, Union Court, Old Broad Street
1865	WALLES, Henry	17, Eagle Wharf Road, Hoxton
1863	WARREN, Charles George	Town Hall, Croydon
1863	WESTON, James W.	6, Victoria Street, Westminster, S.W.
1863	WILLIAMS, Ernest.....	9, Burton Road, Brixton, S.
1863	WISE, W. Lloyd	Chandos Chambers, Buckingham Street, Adelphi, W.C.
1865	WRIGHT, William.....	8, Little Queen Street, S.W.

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THE SOCIETY'S ACCOUNTS FOR 1866.

SUBSCRIPTION ACCOUNT, 1866.

	£	s.	d.
Arrears due on 1st January, 1866	132	5	0
Subscriptions due from Members, Associates, and Foreign Members	586	5	0
Subscriptions due from Life Members	10	10	0
Admission Fees due from Members, Associates, and Foreign Members	69	0	0
Subscriptions in advance	18	12	0
	£816	12	0

	£	s.	d.
Received in 1865 for 1866	25	14	6
Received for Subscriptions and Arrears	395	3	6
Received for Admission Fees	61	12	6
Received for Life Subscriptions	10	10	0
In advance for 1867	18	12	0
Written off—			
Members *deceased*	4	14	6
In accordance with Rule 32	41	19	6
Balance Arrears due	258	5	6
	£816	12	0

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RECEIPTS AND EXPENDITURE FOR 1866.

		£	s.	d.
Balance, January, 1866:—				
On Deposit	£192 2 2			
Cash in hand	49 5 10			
		241	8	0
Received for Life Subscriptions		10	10	0
Received for Annual Subscriptions		395	3	6
Received for Admission Fees		61	12	6
Received in advance for 1867		18	12	0
Received from Messrs. E. & F. N. Spon, for the Sale of the Society's Transactions		30	18	0
Interest on Deposit at Bank		9	12	0
Permanent Fund		140	13	0
		£908	9	0

	£	s.	d.
By Rent of Hall	39	11	0
Commission for Collection of Subscriptions	24	5	10
Advertisements	37	14	0
Short-hand Writer	25	4	0
Printing Papers, &c., and Lithographing Diagrams for 1864 and 1865	239	16	9
Stationery, Printing Rules, &c.	36	2	6
Postage	31	2	5
Wages, Fees, &c.	12	14	9
Premiums	13	10	0
Sundries	27	2	1
Balance on Deposit at Bank	347	12	2
„ Cash in hand	73	13	6
	£908	9	0

Examined and found correct, GEORGE W. ALLAN, *Auditor.*

January, 1867.

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PERMANENT FUND.

ESTABLISHED 1865.

SUBSCRIPTIONS RECEIVED.

	£	s.	d.
ROBERT BROAD	10	10	0
FREDERICK W. BRYANT	10	10	0
WILLIAM T. CARRINGTON	10	10	0
ROBERT M. CHRISTIE	10	10	0
ZERAH COLBURN	10	10	0
BRYAN DONKIN	1	0	0
WILLIAM ESSON	2	2	0
JOHN FARMER	5	5	0
F. H. HARTLEY	1	1	0
J. H. C. B. HORNIBROOK	1	1	0
F. E. HOUGHTON	3	3	0
B. D. KERSHAW	1	1	0
ALBERT LATHAM	2	2	0
BALDWIN LATHAM	15	15	0
WILLIAM H. LE FEUVRE	10	10	0
EDWARD J. LEONARD	1	1	0
JAMES LUND	1	1	0
HENRY MILLER	1	1	0
NEWBERY and ALEXANDER	3	3	0
PERRY F. NURSEY	3	3	0
SAMUEL OWENS	10	10	0
LEWIS OLRICK	5	5	0
HENRY PEAK	1	1	0
JOHN PENN	10	10	0
WILLIAM PICKERING	5	5	0
SYDNEY A. READE	1	1	0
E. and F. N. SPON	10	10	0
CHARLES WHITING	3	3	0
ALFRED WILLIAMS	10	10	0
A. C. WYLIE	2	2	0

SUBSCRIPTIONS PROMISED.

	£	s.	d.
THOMAS D. JONES	10	10	0
ROWLAND M. ORDISH	10	10	0
VAUGHAN PENDRED and £1 1s. Annually	3	3	0
JOSEPH QUICK, Jun.	10	10	0
JOHN SMITH	1	1	0
CHARLES G. WARREN	1	1	0
A. F. WILSON	5	5	0

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TRANSACTIONS, &c.

January 22nd, 1866.

INAUGURAL ADDRESS.

By ZERAH COLBURN, PRESIDENT.

THIS being the first meeting of the Society for the present year, Mr. W. T. Carrington, the retiring President, occupied the chair. After the usual routine business of the meeting, which consisted in reading the accounts, &c., for the past year, the president presented the premiums which had been adjudged to members for papers read during the session 1864-5. These premiums, consisting of books, were awarded to Mr. Charles D. Abel, for a paper on the "Patent Laws;" to Mr. Perry F. Nursey, for a paper on "Sugar Machinery;" and to Mr. Lewis Olrick, for a paper on "Giffard's Injector." Mr. Carrington then vacated the chair, and introduced the President for 1866, Mr. Zerah Colburn, who delivered his inaugural address as follows:—

It is not necessary that I enlarge here upon the past progress nor upon the probable future of the engineering profession, nor shall I detain you with a review of the engineering works achieved last year, nor with a list of what is to be attempted this year. All these you are in the habit of reading in the newspapers, and I need only say, if it be considered necessary in my position to say it, that I believe the profession of engineering is now established upon a footing which will ensure the success of every qualified person who adopts it and practises it rightly and well. What, I think, should be particularly addressed to members of this Society on an occasion like this are some remarks upon the possible development and probable future of the Society itself. It is now in its eleventh year, and it already counts a large number of members, and is in receipt of a considerable annual income. So far the Society has been exceptionally fortunate in having enjoyed the benefit of the unceasing labours of the honorary secretary, Mr. Williams, and but for his services,

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exerted in every manner that could secure the best interests of this Society, it might, I am inclined to believe, have fallen to the ground long ago. I say this quite apart from any complimentary considerations, and merely because it must enter into our estimate of the future position of the Society. We occupy, as a Society, a somewhat exceptional position. Only a small proportion of our number are engaged in the design and conduct of engineering works upon their own account. I am glad, however, to see that our numbers are now being steadily recruited by gentlemen engaged in actual practice. The value of a Society like this is in its power of concentrating professional talent, in influencing it in new directions, and in securing public respect and confidence. Now this can be done only by deserving both. Unless it can be seen that successfully executed works are described here and discussed by those who are competent to do so, we cannot expect to take the rank which, as a Society, we all wish to have before the world. We have had read here many papers, exhibiting much industry in their preparation, papers containing unexceptionable truths, yet these papers have been, in many cases, compilations, instead of being prepared from the special knowledge of their authors. Not but that the Society is under obligations to whoever prepares and reads a paper which is not in itself unsound. Members should dismiss from their minds any idea that they are doing a favour to the Society in preparing papers for reading and discussion, although the Society may and probably does derive some actual benefit from the papers, but they should be prepared from a sense of duty, and as but a fair contribution towards the interest and usefulness of the proceedings. Those who will take the trouble to put upon paper any subject which they really understand, cannot fail, too, to derive advantage from doing so. The preparation of papers disciplines the mind, and compels the writer to choose his forms of expression. A facility for this kind of composition, whether natural or acquired, as it may be by practice, is of great value in every sphere of professional life. The ability to give correct expression to sound truths and to good ideas often enables the speaker or writer to influence those who would be otherwise far out of his reach, and thus not only to derive direct advantages for himself, but to advance whatever proper cause he may make the subject of his communication. In this light the preparation of papers by members of this Society is to be regarded as a valuable exercise, and for the sakes of the writers themselves it should be followed whenever time and a good subject can be found. This preparation compels the writer to study and to reflect, and is in many ways an excellent means of self-improvement.

The course which I have endeavoured to point out is the one

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which, along with some other circumstances, has brought the parent Society, the Institution of Civil Engineers, to its present high position. It might, indeed, be asked why a further society like ours should be needed at all, but I believe that our meetings furnish additional and valuable opportunities, more especially for the younger members, which the Institution, useful as it is, can, nevertheless, hardly afford so well as this Society. However we may secure the co-operation of gentlemen in actual practice as engineers, we shall always be represented, upon the whole, by a much younger class of men than those forming the Institution. And our subjects for discussion will also embrace more works of mechanical engineering, and it may, indeed, be said that ours is the only professional body in London which habitually does deal with mechanical engineering. Our meetings give opportunities for the expression of opinions, and for practice in discussion, which could not be expected, at least by the younger members, at the Institution. Our past success is, indeed, sufficient to show that, properly conducted in the future, the Society of Engineers has no need to fear that its position will not be duly recognised, and the value of its proceedings acknowledged by the profession. Any idea of rivalry with the parent Society, as we may all call the Institution, can never, I feel sure, have been entertained for a moment by any one among us.

The demand for all kinds of professional knowledge is now greater than ever, and this Society enjoys many facilities for collecting and disseminating such knowledge, and thus far commanding the general respect and confidence of the profession. The Society will do much for those, and they are perhaps the majority of the younger engineers, most of whose instruction in their future profession is self-instruction. It will not only bring before them subjects which are new to them, but the discussions will lead them to reflect and compare one thing with another, and to push further inquiries, and to cultivate a habit of reading. I believe that in this way the Society has already accomplished a great amount of positive good, although we may have no precise means of estimating it. I believe that nearly every one of our members who has habitually attended our meetings, and preserved our volumes of Transactions, will own that he has derived direct personal benefit from what he has heard here, and it is by improving, as the Council now believe they see the way to improving, the preparation of papers and the tone of the discussions that these benefits will become more and more distinctly recognised and appreciated. It should be the wish of every member to co-operate in the plans of the Council, so as to bring this Society into a position where its membership will be publicly regarded as a beneficial distinction, by giving an assurance of pro-

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fessional fitness for such works as the members may undertake.

In looking about us upon the works which are already in progress, and in looking forward to those upon which the younger members are likely to be yet engaged, we cannot fail to be struck with the increasing scope which our profession offers. Never before were so many, so extensive, and so varied engineering works in hand; never before have so many new works been contemplated. Improved machinery and improved processes are so cheapening almost every kind of production, in the getting of coal, in the working of metals, in the manufacture of bricks, glass, paper, &c., in agricultural operations, and in the means of communication, that we are adding to our national capital faster than ever before. It is impossible, indeed, to define the limits within which invention, as applied by civil and mechanical engineers—for whether they are inventors themselves or no, engineers are the best fitted to carry most inventions into practice—it is impossible to say within what limits inventions thus applied is now adding to the permanent wealth of the nation. What the steam-engine, the spinning-frame, the power-loom, and the iron-rolling mill have done for Great Britain is really beyond our powers of estimation. Then came a later series of inventions of not less importance—gas-lighting, the locomotive engine, the steam printing-press, the hot-blast, ocean steam navigation, and the electric telegraph. Still later we have had the reaping machine, the steam plough, and the Bessemer process. Each and all of these has done, is doing, and will in future time continue to do more for the good of mankind than was accomplished by all the art and skill of the two thousand years of the world's history previous to the time of Watt, excepting only the invention of printing and the discovery of the mariner's compass. It is engineers who are turning all these grand inventions to practical account for the useful purposes of man, and in many cases engineers are themselves the inventors of new processes and machinery. A great secret of professional success consists in knowing how to improve upon previous practice, whether by invention off-hand, or, more commonly, by that course of elaborate thought and comparison which results in what the engineer prefers to call design. Not that the inventive power is indispensable to success, but when controlled and regulated by good knowledge and sound judgment it is a great aid. Many of the members of this Society are now at an age—and I am speaking of the younger members—when new inventions, once studied and understood, make the most permanent impression upon the mind. There is enough now that, if not absolutely new, is but now beginning to attract general attention, or which, at most, has not

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been for any great length of time before the world. The young engineer should make himself conversant with the contemporary inventions of his own time. The new coal-cutting machines, new puddling machinery, the Bessemer process, the steam plough, the steam fire-engine, the pneumatic railway, the universal telegraph, the gas-engine, the Enfield rifle-making machinery, the various patent moulding-machines employed in the large foundries in the North, the recent applications of frictional gearing, the injector and the later improvements made upon it, the newer apparatus for testing iron, the Mont Cenis Railway, Mr. Sturrock's steam tender, &c., should all be well mastered, and the young engineer should have definite opinions upon them all. So of inventions relating to warfare—the construction of the principal kinds of ordnance and their rifled projectiles, the construction of armour sides for ships, of gun-carriages and of turrets. There are also those large engineering questions upon which the younger members of the profession should keep themselves informed—the large bridges now contemplated in many parts of the kingdom, the drainage and water supply of towns, and especially of the metropolis, the improvement of rivers and harbours, and the great question of ocean telegraphy. In touching thus briefly, and almost without regard to their relative importance, such a number of subjects to which the minds of so many of the members of this Society may be profitably directed, I do so more to suggest the opportunities for, as well as the value of, constant thought. It is the power of thinking closely and for practical purpose that gives to the engineer his ability to deal with fresh difficulties as they arise, and if the younger members of this Society have made up their minds that the opportunities for engineers are to be greater than ever in the future, they must also bear in mind that the preparation for the duties of our profession must also be more complete than ever. To this end we may all hope that the Society of Engineers, as an establishment or an institution, may in future be enabled to render greater services in the advancement of engineering knowledge than ever before.

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February 5th, 1866.

ZERAH COLBURN, PRESIDENT, IN THE CHAIR.

ON THE FRICTION OF THE SLIDE-VALVE AND ITS APPENDAGES.

BY THOMAS ADAMS.

THE slide-valve, as at present almost universally used on the steam-engine, was invented by William Murdock, of the Soho Works at Smethwick, near Birmingham, about the year 1784. It was first set to work without either lap or lead. But subsequently he added a sixteenth of an inch of lap, and again he added a sixteenth of lead, and in that state he left it. And, although engineers since that period have extended the proportions of lap and lead, yet the primary elements, lap, lead, and travel, remain as they left the hands of Watt's companion. Notwithstanding the enormous amount of power required to work this valve and its appendages, engineers prefer it to any other known form, because of the facilities which it affords for a ready admission of steam, any required amount of expansion, and a liberal lead for exhaust, and requiring no other gear to work it than a rod direct from the valve to the eccentric, thus avoiding complication of parts, and ensuring simplicity and certainty of action.

Probably on no portion of the steam-engine has there been spent more time in study, patents, and trials, nor more attempts made which have proved unsuccessful, than that connected with the slide-valve. In fact, there is no engineer of any repute, past or present, who has not devoted some of his time in the endeavour to remove the weight from the back of the valve; but so fickle and deceitful a piece of mechanism has it proved itself to be, that it has hitherto baffled the united skill of all, until at length it was considered impossible to produce a frictionless slide-valve. With such a long list of unsuccessful attempts to look at, it would seem enough to discourage and daunt the most determined, were they not stimulated by that hope of reward which must attend the successful accomplishment of the

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principal and only remaining improvement of worth connected with the anatomy of the steam-engine.

To the accomplishment of this task the author applied himself about four years ago; and he has laboured incessantly in designing and making experiments during the whole of that period, and for nearly three years of that time it completely baffled him, setting all his attempts at defiance, and at length compelled him to leave the beaten path of engineers and seek a new field of discovery in the relation of surface to pressure.

It has been discovered that neither the file, the scraper, pumice-stone, nor the oil-stone, will get up two surfaces of metal sufficiently fine, when moving against pressure, to shut out steam. The steam says, "I am master, and in I will go between your surfaces, and I will not come out, until you apply a force greater than the area of the surface in contact multiplied by the pressure." This is the fundamental principle, the discovery of which produced a frictionless slide-valve.

All engineers are of one accord in ascribing the loss of a large amount of power in working the slide-valve; but there is a large diversity of opinion as to what that amount of power is, solely because there are no correct data from which they may calculate it, as they do other sources of power. A paper on the slide-valve would be incomplete did it not bring within its range the consideration of two questions: firstly, what is the magnitude of the evil of which it complains? and secondly, what is the remedy for that evil? And in setting about such a task, the first thing to be done is to ascertain the co-efficient of friction, under the circumstances attending its practical application; and by that ascertained factor to calculate the amount of work performed by the force expressed by the co-efficient of friction passing through space; and by the time in passing through that space, and upon the principle of work done, find the proportion which that power bears to the total mean power of the piston.

The question is often asked, what is friction? And the answer given is invariably, a certain amount of force, proportional to the weight imposed at right angles to the line of motion, but which proportional force varies not only with a variation in the constitution of the substance, but also with a variation in the weight imposed. And recent experiments show that it varies also with the temperature of the substance employed, increasing in proportion to an increase of temperature. As this proportional force must of necessity depend in a great measure on the geometrical form of the molecules of the substance, an investigation into the constitution of the molecular construction of metals is required.

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The co-efficient of static friction cannot be calculated upon the principle of work done, because it is only a force; and being a force, there must be a limiting angle to it, and that angle will be forty-five degrees, no matter what the form of molecule.

Plate I., Fig. 1. Let A B be a datum line, and E F a line at right angles; from O as a centre, describe the circle A F B E; bisect the arc A F at the point *n*, then the angle A D *n* will be an angle of 45°; draw O *n*, and produce it to P; from P, with the radius O A, describe the circle X Y Z. The centre of molecule, N, will be at an angle of 45° with the line A B. Set off P *p* equal to sine C, and P *p'* equal to cosine C. Let sine and cosine C be the two sides of the parallelogram of pressures, join *p n p' n*, and draw the diagonal P *n* and produce it to O. It passes through the centre of molecule M. It is, therefore, stable. Similarly, from O as a centre, construct the parallelogram of forces to resist those of molecule N, and the diagonal O *n*, produced also, passes through the centre, P, of N, and tangent C is equal and opposite to tangent D. The forces and resistances are equal and opposite, and balance each other. They must, therefore, be in a state of rest, because there is no force on either side capable of producing motion, and hence 45° is the limiting angle of friction; and from this the co-efficient of friction must be calculated, because the sine of this angle and not radius is unity.

Plate I., Fig. 2, is the spherical form of molecules, and the greatest angle of contact is 30°. The mean static co-efficient of friction of N in passing over M is found to be ·2973 of the limiting angle of friction. The parallelogram of forces is here constructed as in Fig. 1.

Plate I., Fig. 3, is the hexagonal form of molecules, and has a higher co-efficient of friction; for while in Fig. 2 the side of the parallelogram of forces, represented by the sine of the angle, decreases from 30° to 5°, while the same side of the hexagonal form remains constant down to 10°, this gives a mean of ·3768 of the limiting angle of friction, and $\frac{\cdot 3768 - \cdot 2973 \times 100}{\cdot 3768} = 21$ per cent. in favour of the hexagonal form. And steel and homogeneous metals, which partake more of the hexagonal form than iron, are therefore better suited for rails and wheel tires of either engines or carriages, and are, in point of wear and tear, practically indestructible.

Plate I., Fig. 4, shows three molecules, neither the hexagon nor the sphere, but partly both, which is, no doubt, the state in which metals exist under the atmospheric temperatures. The arrows show the direction of the motion of the molecules as their centres recede from each other, and the opposite when they approach

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each other; and any one will at once see the friction to be overcome by their rubbing along the flat side. This is molecular friction, and this force has to be overcome, whether the molecules be subjected to an increase of temperature or an increase in the polar forces, or by the force of tension or by compression.

With this preliminary investigation into the nature of friction, we will proceed with the subject of the paper.

What is the amount of power absorbed in working the slide-valves and appendages of the steam-engine?

To ascertain this, the author had a cylinder-face, valve-box, and valves made, for the purpose of experimenting upon a variety of forms of valves; and the records of the Patent Office show that, during the period of these experiments, lasting nearly four years, no less than four distinct patents have been taken out as those experiments advanced in improvement.

To carry out these experiments, a chain was attached to the valve-spindle and passing over a pulley, on which was hung a scale, into which weights were placed, until motion of valve was produced, the valve being at all times started from its middle position. The bearing surface of the valve is one-half of the back, or 50 sq. in., which gave, with 60 lb. of steam, a pressure of 120 lb. per square inch, the area of the valve being 100 sq. in. The valve was then recessed in the face, leaving only a strip all round it of three-eighths of an inch, equal to one-seventh the area of the back, which, with 60 lb. of steam, was equal to a pressure of 420 lb. per square inch.

	Table No. 1.					Table No. 2.	
	Cast Iron on Cast Iron.					Brass on Cast Iron.	
No.	Pressure of Steam.	Pressure per Square Inch. 1st Series.	Co-efficient of Friction. 1st Series.	Pressure per Square Inch. 2nd Series.	Co-efficient of Friction. 2nd Series.	Co-efficient of Friction. 1st Series.	Co-efficient of Friction. 2nd Series.
1	10	20	·206	70	·235	·184	·210
2	20	40	·218	140	·260	·191	·239
3	30	60	·232	210	·287	·213	·263
4	40	80	·241	280	·311	·220	·288
5	50	100	·256	350	·349	·227	·325
6	60	120	·269	420	·362	·236	·354

Table No. 1 is cast iron upon cast iron. The first column is the number, the second the pressure of steam, the third the pressure per square inch of bearing surface, the fourth the co-efficient of friction, the fifth the pressure per square inch of bearing surface of the valve reduced, and the sixth is the co-efficient of friction of the second series. Table No. 2 is brass

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upon cast iron. The first column is the co-efficient of friction of the first series, and the second the co-efficient of friction of the second series. The results are the mean of ten trials each, and care was taken that no lubricant of any kind was present, nor moisture in the steam—the trials being made only when good blue steam showed itself at the petcock, and the co-efficient of friction was taken at the point where motion began. With steam of 10 lb. pressure, with a temperature of 240° and a pressure per square inch of rubbing surface of 20 lb., cast iron on cast iron gave a co-efficient of ·206; at the same temperature and 70 lb. per square inch of bearing surface, it gave a co-efficient of friction of ·235; with 60 lb. of steam, and at a temperature of 381° and a pressure of rubbing surface of 120 lb. per square inch, it gave a co-efficient of friction of ·269; at the same temperature, and with a pressure of 420 lb. per square inch of surface, it gave a co-efficient of ·362. With brass upon cast iron, the corresponding temperatures and pressures gave corresponding co-efficients of friction of ·184, ·210, ·236, and ·354, showing that, as the temperature rises, the co-efficients approach nearer to each other. With the valve as in the first series, and with a V-piece cut out to admit steam into both admission ports, and a hole in back of valve to let the steam through into the exhaust, and all three cocks shut, the valve moved as easily with steam on, as off; showing that, without the exhaust cavity and ports, the valve will be practically frictionless. This experiment was only lately tried, to prove the principle of the frictionless slide-valve.

It is quite natural that the co-efficient of friction should increase with an increase of temperature, because an increase of heat is synonymous with a decrease in cohesive force of the molecules, and it at the same time proves that the asperities of the metals in contact are more easily knocked off. A greater or less number of these molecules are set at liberty every stroke, and this causes the co-efficient of friction never to be twice alike, and so practical friction is a compound of true friction and crushing. There is abundance of evidence of this in the application of superheated steam, by the excessive wear of the surfaces in contact, since the excess of heat lessens the cohesive force of the molecules, and the increase in the co-efficient of friction, and the dryness of the steam, banishes the very idea of a lubricant. If the temperature of the steam, whether saturated or superheated, be carried high enough, we should have the cohesive power of the molecules utterly destroyed, and the metal would then exist in a liquid state. Extremes are always good for illustration. But there is a temperature at which the co-efficient of friction and the cohesive force of the molecules will

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balance each other; but between this temperature and that of fluidity the co-efficient of friction decreases, and the destruction of the molecules will increase, which would be manifest by an increase in wear and tear. This, doubtless, takes place in many cases of superheating. The nature of cast iron is such, that its composition can be varied to give a co-efficient of friction on dry, hot surfaces, ranging from ·18 to ·21, according to the closeness, texture, and hardness of the composition.

Plate II., Figs. 5, 6, 7, represent the valve of No. 47 Engine, North London Railway, the dimensions of which are, diameter of cylinder, 17 in.; stroke, 24 in.; lap of valve, $\frac{7}{8}$ in.; lead, $\frac{1}{8}$ in.; travel, 4 in.; position of gear, 4th notch from mid-gear, there being 5 notches for fore and 5 for back gear from the central one; diameter of driving-wheel, 5 ft. 6 in.; number of revolutions, 140; pressure in boiler, 160 lb. per square inch.

Fig. 5 is a section of the valve over the ports in middle position. Fig. 7 is a plan of the same, looking at the face. Fig. 6 is a section of valve over the ports at commencement of stroke.

The outer and inner edges of the valve, by their crossing the outer and inner edges of the ports and bars on the cylinder face, determine the distribution of the steam.

If we draw lines, *m n*, from each of those edges, at right angles to the plane of the valve's motion, and at any convenient distance below and on the lines, drawn from the outer and inner edges of the valve, while in its middle position describe semicircles, E, &c., equal to the travel of valve; divide these semicircles into ten equal parts, each corresponding to the ten equal divisions on the indicator, diagram Fig. 8. Let the pressure on the back of the valve be represented as positive pressure, and that on the face and in the exhaust cavity as negative pressure. Measure the horizontal distances from each division to the edge of port or bar, and find what section of surface of valve is exposed to negative pressure. That section multiplied by the length of the port, and by the corresponding pressure on diagram, will give the total negative pressure, which, taken for the ten divisions, and their mean subtracted from the total positive pressure, will leave the positive force available for friction, which, multiplied by the co-efficient of friction and by the feet passed through by the valve per minute, and divided by 33,000, will give the horse power required to move the valve.

Similarly for the eccentric. The positive force of the valve multiplied by the co-efficient of friction will be equal to the direct pull or force on the eccentric, and this force multiplied by the co-efficient of friction due to a cold lubricated surface, and by the space passed through by the periphery of the eccentric

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in feet per minute, and divided by 33,000, will give the horse power required to work the eccentric. Let S be the centre of the axle, and S C the length of the crank; then will C O C be the path of the crank-pin, and C C the stroke of piston.

Fig. 8. Divide the diagram Fig. 8 into ten equal parts, and draw ordinates, marking on them the respective pressures and back pressures, and find the horse power of the cylinder, care being taken that the same mode of finding the horse power of the friction of valves and eccentrics be used.

The total mean negative pressure is 1891·14 lb., and this pressure subtracted from the total pressure on back of valve leaves the force available for friction thus: $18\frac{5}{8} \times 9\frac{7}{8} \times 160 = 29440 - 1891{\cdot}14 = 27548{\cdot}86$.

The mean number of inches in the valve bearing on the cylinder face being 64·8, then $\frac{27548{\cdot}86}{64{\cdot}8} = 426$ lb. per sq. in., and from this figure we obtain the co-efficient of friction of brass on cast iron, viz. ·354. Next ascertain the mean pressure in the diagram, and the mean of the back pressure in same, and subtracting the lesser from the greater, and dividing by 10, gives the mean pressure in the cylinder. Then the following is the calculation: $18\frac{5}{8} \times 9\frac{7}{8} \times 160 = 29440$, and $29440 - 1891{\cdot}14 = 27548{\cdot}86$, and $\frac{27548{\cdot}86 \times {\cdot}354 \times \frac{8}{12} \times 140}{33000} = 27{\cdot}476 \text{ HP} \times 2$ for two valves $=$ 54·952 HP = friction of both valves.

The eccentrics are 16 in. diameter and $2\frac{3}{4}$ in. broad. The bearing of the eccentric strap is equal to $16 \times 2\frac{3}{4} = 44$ sq. in. of bearing surface; and is equal to $\frac{27548{\cdot}86 \times {\cdot}354}{44} = 221$ lb. per square inch.

As no experiments were made to determine the co-efficient of friction of the eccentric, it is taken at a low number, ·15 being a cold lubricated surface. Then, $27548{\cdot}86 \times {\cdot}354 = 9752{\cdot}296$, and $\frac{9752{\cdot}296 \times {\cdot}15 \times 5{\cdot}5 \times 140}{33000} = 37{\cdot}163 \text{ HP} \times 2 = 74{\cdot}326 \text{ HP}$ = friction of the eccentrics, and $74{\cdot}326 + 54{\cdot}925 = 129{\cdot}251$ HP, equal to the friction of valves and eccentrics, and $\frac{227 \times 109{\cdot}1 \times 560}{33000} =$ 420·266 HP of one cylinder, which, multiplied by 2 = 840·532 HP of both cylinders, and $840{\cdot}532 - 129{\cdot}251 = 711{\cdot}281$, and $\frac{711{\cdot}281 \times 100}{840{\cdot}532} = 84{\cdot}6$ per cent., and $100 - 84{\cdot}6 = 15{\cdot}4$ per cent. of the power of the engine required to work the valves and eccentrics. Thus we see that eccentrics of this diameter exert a greater brake force on the engine than the friction of the

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valves by 20 horse power. But the eccentrics are the unavoidable appendages of the valve, and the loss by the one is the inevitable and certain loss by the other. This is an example of an engine working in one notch from full gear.

The next example is from an express engine on the Great Northern Railway working in the first notch from mid-gear, and running at a speed equal to 55 miles per hour. Diameter of cylinder, 17 in.; stroke, 24 in.; lap of valve, $1\frac{1}{4}$ in.; lead, $\frac{1}{8}$ in.; travel, $3\frac{5}{8}$ in.; diameter of driving wheel, 7 ft.; number of revolutions, 220; pressure in boiler, 160 lb. per square inch. Figs. 9, 10, 11, and 12 represent that valve. Fig. 9 shows it in middle position, with dimensions on it. Fig. 11 is a plan of the same, showing face. Fig. 10 is a section in position at commencement of stroke; below it are semicircles, constructed as before, representing the travel of valve, the larger diameter corresponding to the larger diagram, and the smaller diameter that of the smaller diagram, both at the same speed, for the purpose of comparing the variation which the per-centage of the friction of the valve bears to the per-centage of the cylinder's power, which ranges between 10 and 55 per cent., according to the variation in the position of gear; for while the cylinder decreases in power, the friction of valve and appendages increases, until, by a decrease on the one hand, and an increase on the other, the valves and eccentrics absorb upwards of half the power of the cylinders.

Let Fig. 12 be the diagram taken in the first notch from mid-gear, the pressure per sq. in. of rubbing surface of valve being 431 lb.; the same co-efficient of friction is used as for the other, and the following is the calculation: Dimensions of valve, 20·25 × 11·5 in., then $20{\cdot}25 \times 11{\cdot}5 \times 160 = 37259{\cdot}2$, and $37259{\cdot}2 - 4503 = 32756{\cdot}2$, and $\frac{32756{\cdot}2 \times {\cdot}354 \times \frac{7{\cdot}25}{12} \times 220}{33000} = 46{\cdot}551$ HP $\times 2 = 93{\cdot}102$ HP, equal friction of valves, $32756 \times {\cdot}354 = 11567{\cdot}64$, and $\frac{11567{\cdot}64 \times {\cdot}15 \times 5{\cdot}5 \times 220}{33000} = 63{\cdot}652$ HP $\times 2 = 127{\cdot}304$ HP friction of eccentrics, and $93{\cdot}102 + 127{\cdot}304 = 220{\cdot}406$ HP friction of valves and eccentrics, and $\frac{227 \times 32 \times 880}{33000} = 193{\cdot}44$ HP $\times 2 = 386{\cdot}88$ HP of both cylinders, and $386{\cdot}88 - 220{\cdot}406 = 166{\cdot}474$, and $\frac{166{\cdot}474 \times 100}{386{\cdot}88} = 43$ per cent. for cylinders, $100 - 43 = 57$ per cent. equal friction of valves and eccentrics. It will be seen here that the eccentrics require more power to work them than the valves by 34 horse power.

Thus the friction of the valves and eccentrics, when working

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in this position, is equal to more than half the power of the engine; and the mode of calculation is as correct in the one case as in the other. What is correct for the finding of the power of the cylinder is also correct for the finding of the friction of the valves and eccentrics, since the same rule is applied to both. And the variation in the per-centage of power required to work the valves and appendages ranges, according to the position of gear by the link motion, from about 12 per cent. in full gear to 56 per cent. in the first notch from mid-gear, when running at a high speed producing considerable back pressure.

We will now examine into the proportions of piston-rod and valve spindles, and see how these calculations agree with actual practice, and take, as an example, the North London Railway engine: Diameter of piston-rod, $2\frac{3}{4}$ in.; sectional area, 6 sq. in.; greatest force on piston rod, 36,320 lb. Then, $\frac{36,320}{6}$ = 6053 lb. per square inch of section; diameter of valve spindle, $1\frac{5}{8}$ in.; sectional area in square inches, 2·07; mean force on valve spindle is 9552. Then we have $\frac{9552}{2\cdot07}$ = 4614 lb. per square inch of section, which shows the calculation to favour the relative strength of the valve spindle. Yet we seldom hear of a piston-rod breaking; on the other hand, we are continually hearing of valve spindles breaking. About two months ago, two of those very valve spindles which have just been calculated, broke and doubled up, as if they were no stronger than a willow.

When the dimensions of the Great Northern Railway express engine were taken by the author, it was in the shed being fitted with a new buckle, the old one having broken across at A, Fig. 13; and the sectional area of the buckle only receives one-half of the force, because, the valve spindle being in the centre, the force is equally divided between the two sides of the buckle.

Now the section at A is 2 in. deep by $\frac{3}{4}$ in. thick, equal to $1\frac{1}{2}$ sq. in., and the mean force on the valve spindle is $\frac{11567}{3}$ = 3841 lb. per square inch, while the breaking weight of iron (for these things are made of the best material) of that section is 56,000 lb. per square inch, upwards of fourteen times the calculated force. What then broke it?

The greatest pressure which comes upon the valve is when the bearing surface is 66 sq. in., equal to 496 lb. per square inch of rubbing surface, and this with the metals at a temperature of 370°; these two forces, temperature and pressure, combine together for the purpose of uniting the molecules of the valve and cylinder faces together, and nothing short of it will break

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the spindle, because the total force on the valve, multiplied by the co-efficient of friction, does not amount to one-fourteenth of the breaking weight of the spindle.

Mr. Mathews, of the firm of John Penn and Son, says that this is the true measure of friction (when the spindle comes in two).

Other cases than this have been calculated by the author, who is of opinion that 500 lb. pressure per square inch of bearing surface, with the corresponding temperature of saturation of 160 lb. of steam, is beyond the limits of safety, and is entering on the confines of molecular union of the metals.

And next of the back pressure and compression: the sum of the pressures of the Great Northern express engine is 549, and of the back pressure and compression 228. Now, $549-228=320$, and $\frac{320\times100}{548}=58{\cdot}4$ per cent., $100-58{\cdot}4=41{\cdot}6$ per cent., which is the proportion of back pressure to total pressure, and $\frac{227\times22{\cdot}8\times880}{33000}=138\text{ HP}\times2=276\text{ HP}=$ back pressure, which, added to friction of valves and eccentrics, $=496$ HP. The total force of the steam on the propelling side of the piston is $\frac{227\times54{\cdot}9\times880}{33000}=361\text{ HP}\times2=722\text{ HP}$ for both cylinders, and $772-496=226$, and $\frac{226\times100}{772}=31{\cdot}3$ per cent. of the power of the steam used for commercial purposes.

The cause of back pressure is the want of a copious exhaust, and the compression is regulated by the final pressure of exhaust and by the amount of lap of valve; an increase in one or both those sources of evil only aggravates the mean back pressure. Where expansion is performed by lap of a single valve, the period of compression is unavoidable.

For that purpose it is necessary to have a large exhaust passage, and to keep it open during the whole, or nearly the whole, of the stroke. Fig. 14 is a section of two valves, the one working on the other; the inner valve regulates the admission, exhaust and compression, exercising the same functions as a valve with no lap, and is driven by an eccentric. If lead for the exhaust be required, it may be given by inside clearance; and if requiring more than could be afforded by that means, then it may be done by increasing the angle of advance of the eccentric. The outer valve regulates the suppression; and its linear advance may be varied to any required amount for an admission of steam, ranging between the minimum and maximum limits of a suppression at 1 per cent., or 99 per cent. of stroke of piston, or any intermediate per-centage. Fig. 15 is a plan of the inner valve.

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We will now take an example of the marine engine, and for that purpose we will select the engines of the *Warrior* (iron-clad).

Effective diameter of cylinder 104¼ in., stroke 4 ft., revolutions 56 per minute, lap of valve 5¾ in., lead in full gear 1 in., travel 20 in., pressure in boiler 27 lb. per square inch.

Engines by other makers could have been selected, from which a much larger per-centage of friction would have been got. But the *Warrior* is selected, because her engines are acknowledged to be of the very best description made, both as regards design and workmanship; and if the ordinary valve-packing could be made and kept steam-tight, it would be done by the builders of these engines.

Plate III., Fig. 1, is a section of the valve, the dimensions of which are approximately correct, and shown in position at commencement of stroke. The valve is 50 in. by 79 in. Below Fig. 1 describe semicircles as before, representing the travel of valve, and divide them into ten equal positions corresponding to the ten divisions on the diagram. The pressure on this diagram are all taken from the zero line; by so doing, the same mode of calculation is used as for the high-pressure engine. The valve being cast iron on cast iron, and the pressure per square inch of surface being 121 lb., the co-efficient nearest to this is ·260.

The space passed through by the periphery of the eccentrics is equal to the circumference of a circle, described by a radius equal to the distance between the centre of the shaft and the periphery of eccentric at its highest part. In other words, it is the circle generated by the highest point of the periphery of the eccentric in its path round the shaft. Many gentlemen will doubtless say that the diameter of the eccentric, which gives the mean frictional periphery, should be the diameter used, and that surface should be taken. This point the author will not dispute. The per-centage of friction is, however, reduced by this standard: thus, for the North London engine it gives 13·2 per cent.; for the Great Northern, 50·4 per cent.; and for the *Warrior*, 10·8 per cent.; and, were the North London Railway engine thrown into full gear, the per-centage of friction would be reduced to about 12 per cent. So that the per-centage of friction by the link-motion arrangement varies from a minimum of 12 per cent. in full gear to 50 per cent. in the first notch from mid-gear. In judging of the friction by reversing an engine with steam on, we do not overcome more than half the power represented by friction, because we can only move the valves and practically not the eccentrics, because the small arc through which the eccentric straps pass, reduced by the long leverage of the rods, is not worth accounting for, and as the eccentrics represent more than half the frictional power, we can only overcome half that power in reversing.

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TABLE No. 3.—WARRIOR.

No.	LEFT-HAND SIDE. Outside Edge. Breadth in Inches.	Length in Inches.	Pressure in Pounds.	Total.	Inside Edge. Breadth in Inches.	Length in Inches.	Pressure in Pounds.	Total.	RIGHT-HAND SIDE. Inside Edge. Breadth in Inches.	Length in Inches.	Pressure in Pounds.	Total.	Outside Edge. Breadth in Inches.	Length in Inches.	Pressure in Pounds.	Total.	B. Surface in Square Inches.	Pressure in Cylinder.	Back Pressure.
1	6	74	34	15,096	3·8	74	6·5	1,827	25	74	6·5	12,025	6·1	74	4·2	18,958	1,033	34	6·5
2	3·25	74	37·6	9,042	4·5	74	6	1,998	25	74	6	11,100	7·6	74	4·2	23,610	954	37·6	6
3	2·75	74	37	7,557	5·2	74	5·6	2,160	25	74	5·6	10,175	8·2	74	4·2	25,485	875	37	5·6
4	3	74	36	7,992	4·6	74	5·3	1,764	25	74	5·3	9,805	8	74	4·2	24,864	954	36	5·3
5	4·3	74	35	11,137	3·5	74	5·1	1,320	25	74	5·1	9,435	6·6	74	4·2	20,512	1,010	35	5·1
6	6·4	74	31·5	10,918	1·3	74	4·8	4,660	25·5	74	4·8	9,057	4·6	74	4·2	14,296	1,112	31·5	4·8
7	7	74	25·4	13,157	...	...	...	...	28·3	74	4·6	9,632	2·1	74	4·2	6,526	1,191	25·4	4·6
8	7	74	21·6	11,188	...	...	...	...	31·4	74	4·5	10,456	...	...	...	...	1,112	21·6	4·5
9	1	74	42	3,108	29·6	74	19·3	47,274	7	74	4	2,072	...	...	...	...	1,155	19·3	4
10	3·5	74	42	10,878	26·6	74	15	16,650	7	74	7	3,626	...	...	...	...	1,112	15	7
				100,033				73,453				87,383				134,251	10,508	292·4	53·4
				73,453														53·4	
				87,383															
				134,251														239	
				395,120														10	=23·9
				10	=39,512 negative pressure.														

$79 \times 50 \times 42 = 165{,}900$, and $165{,}900 - 39{,}512 = 126{,}388$, and $\frac{126{,}388 \times \cdot 260 \times 3\cdot 333 \times 56}{33000} = 185\cdot 7 \text{ HP} \times 2 = 371\cdot 4 \text{ HP}$ = friction of valves.

$126{,}388 \times \cdot 260 = 32{,}861$, and $\frac{32861 \times \cdot 15 \times 17\cdot 54 \times 56}{33000} = 146\cdot 715 \text{ HP} \times 2 = 293\cdot 63 \text{ HP}$ = friction of eccentrics. $371\cdot 4 + 293\cdot 63 = 665\cdot 03$ HP = friction of valves and eccentrics. Next, $104\cdot 25^2 \times \cdot 7854 = 8375\cdot 75$, and $\frac{8375\cdot 75 \times 23\cdot 9 \times 448}{33000} = 2704 \text{ HP} \times 2 = 5410$ HP of both cylinders.

$5410 - 665\cdot 03 = 4744\cdot 97$, and $\frac{4744\cdot 97 \times 100}{5410} = 87\cdot 7$ per cent. for cylinders. $100 - 87\cdot 7 = 12\cdot 3$ per cent. for valves and eccentrics.

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The above Table No. 3 gives the results as shown at foot of table.

It will be seen that the valves require a greater amount of power to work them in this case than the eccentrics, the reason being, that, in the former case, the proportion of travel of valve to diameter of eccentric is about 1 to 4; in this case it is about 1 to $2\frac{1}{4}$, which quite accounts for the difference.

It will be seen that no deduction is made for the packing on the back of the valve. The author wishes it to be distinctly understood that there is no elastic vegetable packing on the back of the slide-valve, which is steam-tight in practice, no matter by what maker. It has a ring at the bottom; Tuck's packing, india-rubber, or gasket above that; and another ring above all, working against the door, with the usual ratchet collar and spring, and set screws for setting it up with.

A small hole, $\frac{1}{2}$ in. diameter, is drilled in the back of the valve into the exhaust cavity, for the purpose of bringing the vacuum through on to the back of the valve, but this is, in reality, continually blowing a column of steam into the condenser. In the case of the *Warrior*, this hole, not being sufficient to carry the steam from the back, a cock, C, $2\frac{1}{2}$ in. in diameter, was fitted on to the door opposite the centre of valve, and communicating with the condenser. This cock, when opened, relieved the valve; but so large was the amount of steam sent into the condenser by two $2\frac{1}{2}$ in. pipes, that it immediately destroyed the vacuum. On shutting them, the pressure accumulated on the back of the valve, inside the packing-ring.

The valve has, therefore, been considered as having all its normal pressure on it. Let us look at this question from a commercial point of view, and see what the friction of these valves mean, on the first cost of the engines, and on the fuel consumed to maintain that friction. It is evident that engines giving an indicated horse power equal to 4744·97, with frictionless slide-valves, will be as effective in propelling the ship as those of 5410 indicated horse power, with the ordinary valves.

Now the indicated power divided by the nominal gives the ratio, and $\frac{5410}{1250}=4{\cdot}32$, and $\frac{655}{4{\cdot}32}=154$ nominal horse power; so that engines of 1096 horse power nominal, with frictionless slide-valves and appendages, would be as effective as those of 1250, and 154×60 pounds sterling per horse power $= 9240l.$, which would be saved in the cost price.

The engines of the *Warrior* consume $4\frac{1}{2}$ lb. of Welsh coal per indicated horse power per hour;

$$\frac{665 \times 4\frac{1}{2}}{2240}=1 \text{ ton } 6 \text{ cwt. } 1 \text{ qr. } 7 \text{ lb.}$$

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of coal per hour, saved by the application of frictionless slide-valves, which, at 1*l.* per ton, is equal to 31*l.* 12s. per day, which, were she steaming two-thirds of her time, would amount to 7710*l.* per year, with packing at 3s. 6d. per lb., and repairs to maintain the present valve and appendages at 50*l.* per year, is equal to 7760*l.*

The firm of Ravenhill, Salkield, and Co. lately applied a pair of 24-inch diameter cylinders to reverse the valves of a Turkish iron-clad, 800-horse power, lately fitted out by them, with 25 lb. of steam and 13 lb. of vacuum; the two cylinders exert a force equal to 34,350 lb. The two cylinders were, however, utterly helpless; they were not able to move the valves with steam on, for which they were intended, in order to reverse the engines rapidly.

Messrs. Humphrys and Tennant, of Deptford, fitted up the engines of the *Mooltan*, 400-horse power, with a 10-inch hydraulic press for reversing, notwithstanding the valves had the usual packing-rings at the back. This press was equal to a force of 84,000 lb., and reversed the valves with steam on, but required twenty seconds of time from full gear ahead to full gear astern.

This, then, is the evil of which the paper complains. Its next step is for the remedy.

There is no word more potent with meaning than the word equilibrium. It admits of no intermediate solution in its meaning. It means the balance of forces, whether in a state of rest or of motion. It is nature's first and grandest law, and by it the order of matter in motion is maintained.

Fig. 16 is a section of the valve, of which Fig. 17 is a plan. It consists of a rectangular block, with the exhaust cavity cut out.

We will now consider whether a plain ring on the back of the valve, and working against the door, will or will not be steam tight. The ring is three-quarters of an inch thick, and two flat springs are put under it to keep it up to the door, and the surface bearing against the door is three-quarters broad. Steam of low pressure is let in, and all is tight; the pressure gradually rises, and at 26 lb. per square inch a blow commences. The higher the pressure now rises, the greater the blow. The ring is now taken out, and a quarter of an inch all round the inside is cut out in the lathe a quarter inch deep, as shown at D. It is now put into its place again, with the same springs under it, giving it the same force against the door, but only half an inch instead of three-quarters. Steam is let in, and at 26 lb. it is tight, and at 30 lb. also; but as the pressure rises, and the gauge shows 40 lb., a leak is discovered, the pressure rises, and the

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blow becomes stronger. The ring is again taken out, and another quarter of an inch recessed out of the inside, as shown at E, leaving only a quarter of an inch to bear against the door. With surfaces properly got up, this is quite sufficient breadth to keep tight. With the same springs again under the ring, 60 lb. pressure did not produce a blow, but the author had every reason to believe it would take place at about 78 lb. This was the experiment which determined the relative surfaces of both valve and ring; which showed, without the least doubt, that the steam insinuates itself, when the valve moves against pressure, between the surfaces.

Fig. 18 is a section of a valve in middle position over the ports fitted for Mr. Cowan, of the Great North of Scotland Railway, and proportioned so as to work easier with steam of any pressure on it than when steam is shut off, and to be steam tight, and beyond the reach of a break down from causes attending working, and to be cheap of construction; the valve being arranged so that the whole of the labour in getting up is done by machinery; the mode of construction being, to plane the face and edges. If out of winding it requires no filing or scraping, chuck it in the lathe, and bore and turn it. The buckle is a hoop of iron, bored in the lathe, and the spindles turned. The ring is cut with a butt joint, an eighth of an inch to the foot diameter being cut out; the ring is closed by chucking it in lathe, where it is bored and turned to fit its place in valve. Put two flat springs under the ring, and the valve will be finished. It requires no getting up by hand tools. Fig. 18 shows a fillet, F, on the ring, the steam being allowed to act under the fillet, so as to keep it up against the door.

The ring R being recessed inside as shown, the exhaust pressure of a high-pressure engine and the vacuum of a low-pressure engine act equally on the top and bottom sides, holding it in equilibrium. Thus the ring is balanced.

As soon as motion of the valve takes place against the pressure, the steam exerts its force between the surfaces. If the valve receded before the pressure, as in a piston, then a force pressing the ring against the door equal to the exhaust pressure would be sufficient, as is the case with a piston: but most pistons, except Ramsbottom's, or those similar to that used on the North London Railway, leak when heavy compression sets in, and the pressure at which they will leak will depend on the force pressing the metallic ring against the sides of the cylinder, and the repeated compressing of the metallic ring during compression is the cause of those pistons, which have springs to keep them tight, having to be so often set up.

In a valve box full of steam there is a film adhering to the

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surface of the metal. So long as that film possesses the temperature of the steam, no matter how thin it may be, it possesses the pressure of the surrounding steam, and a valve sliding along the surface, slides on this film, and that is the reason why the author's valve works easier when steam is on than when steam is off.

Experiments have been made by the author to determine this by exposing the surface of the cylinder to a cooling process, in order to destroy the temperature of this film, but when cooled so as to condense the film, it loses its force.

Experiments have also been made with a view to squeeze out the film by pressure. This pressure varies with the condition of the steam, being least with superheated steam, and greatest with moist steam; but in no case does it take more than thirty-four per cent. above the balance to do so, and when squeezed out, friction sets in all at once, with a force equal to the whole pressure imposed. This film, while it exists, acts the part of a lubricant, but the force which will destroy it, is the amount of work done. It is an elastic fluid, possessed of heat, and will give off an amount of energy equal to the mechanical equivalent of its heat. It will therefore only carry a certain weight, which it does as the valve slides over it, and when its heat is destroyed, friction sets in.

February 19*th*, 1866.

ZERAH COLBURN, PRESIDENT, IN THE CHAIR.

ON THE FRICTION OF THE SLIDE-VALVE AND ITS APPENDAGES.

BY THOMAS ADAMS.

DISCUSSION.

Mr. JENSEN said that Mr. Adams raised several important questions, on which he should like to offer a few remarks. As an inventor of what was no doubt a very excellent slide-valve, Mr. Adams very properly set about making experiments for himself to ascertain the real friction of a slide-valve. Probably the members of the Society had all been more or less startled with the results obtained. They had hitherto been used to estimate the friction of slide-valves according to the co-efficients found many years since by M. Morin, and they now got, from

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Mr. Adams, co-efficients very much at variance with them, not only in their value by themselves, but perhaps more so on account of their differing from, and quite upsetting, the seemingly well-established law that friction within the limits of actual abrasion was quite the same under all pressures; namely —other circumstances being alike—a certain per-centage of the pressure. It was true that doubt had been thrown on Morin's experiments more than once, but the accepted laws of friction had not been upset. An attempt must, therefore, be made to account for the difference in the co-efficients. First, there was no doubt that temperature had something to do with the discrepancy, but to what extent it was difficult to see. On examining the data given a better clue might be found for them. The friction with 10 lb. pressure of steam, with 240° temperature—the proper temperature for that pressure, showing that there was no superheating—he gives as ·206 and ·235 co-efficients for cast iron on cast iron, for a pressure of, respectively, 20 lb. and 70 lb. per square inch of rubbing surface. These co-efficients are high compared to Morin's, which give ·18 to ·19, but with slightly greasy surfaces; and Morin added that, without that slight lubrication, the surfaces abraded. As this was not mentioned in Mr. Adams's paper, he (Mr. Jensen) supposed there was no abrasion, and that the steam, although blue, did not prevent a slight condensation between the surfaces, but contained just sufficient watery particles to prevent abrasion. These co-efficients seemed not to be much at variance with the old co-efficients given by Morin and other experimenters. But those which followed were very startling: with 60 lb. pressure of steam and 381° of temperature, he got as friction co-efficients ·269 and ·362 for a pressure per square inch of rubbing surface of, respectively, 120 lb. and 420 lb. That the friction should increase so enormously on account of the temperature, which was only 140° more than in the first experiments, was strange; but he (Mr. Jensen) believed it was only on account of the steam being superheated. The steam-tables gave for 60 lb. pressure 307·5°, but Mr. Adams had got 381°; hence the steam must have been 74½° superheated. It could not have had any moisture whatever, and abrasion must have taken place—perhaps not enough to show at once, but it would be manifest after continued working. He could not reconcile these co-efficients with those by Mr. Adams, for hot dry surfaces given further on in the paper, namely, ·18 to ·21, according to the closeness of the texture of the metal. He should be glad to hear any explanation of the discrepancy. Mr. Adams's experiments also gave the friction of surfaces when started from a state of rest; and this was always higher than the friction of surfaces in

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motion. He (Mr. Jensen) thought it was hardly fair to use the high co-efficients found by Mr. Adams in his calculation of the friction of locomotive and marine-engine slide-valves. He used ·354 instead of, according to his own experiments, ·21 or ·18. This would at once reduce the loss by friction to half the amount Mr. Adams stated, and, if the steam was not quite dry, even to a greater extent in locomotives. He (Mr. Jensen) thought the steam was not quite dry in general practice. He had next to note the high-friction co-efficient Mr. Adams used in calculating the friction of eccentrics. Morin gave the friction of cast-iron shafts in gun-metal bearings, more or less lubricated (an analogous case to that of a cast-iron eccentric running in a gun-metal eccentric strap), as ranging from ·054 to ·19, and for shafts lubricated in the ordinary way ·07 to ·08. Mr. Adams used what he called the low co-efficient of ·15, or exactly double. Consequently the friction of eccentrics would have to be reduced another half. Further on, Mr. Adams stated that the positive force of the valve multiplied by the co-efficient of friction would be equal to the direct pull on the eccentric, and this force multiplied by the co-efficient of friction due to a cold lubricated surface, and by the space passed through by the periphery of the eccentric in feet per minute, divided by 33,000, gave the horse power required to work the eccentrics. Now this is not expressed correctly, and can be misunderstood. The rule was this: multiply the load required to work the valve by the circumference of the eccentric in feet, divided by double the stroke of the eccentric in feet; multiply the quotient by the number of revolutions per minute and by the co-efficient of friction due to such a case, and divide by 33,000. The result is the horse power lost in friction of the eccentric. Mr. Adams may or may not have used this rule in his calculation, as he did not show the details of it in the paper. When they came to the consideration of the strength of valve spindles, it seemed obvious that the friction of the valve had nothing to do with it. Although Mr. Adams used very high co-efficients, and thus found the friction to be enormous, still, he said, it was only equivalent to 4600 lb. per square inch of section, which was only $\frac{1}{26}$ of the tensile strength of good steel, and $\frac{1}{52}$ of its strength to resist crushing. We must, consequently, seek for some other reason independent of the friction of the slide-valve. Various reasons might be assigned for it; for instance, hard packing in the spindle stuffing-box, or the presence of grit there; or the exposure to a transverse strain by not being properly guided; or the deteriorating influence of sudden blows many times repeated, either through the presence of water in the cylinder or simply the sudden reversing and stopping of the engine. He (Mr. Jensen) left it to locomotive

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engineers to say whether the sand-box had anything to do with the breakage of spindles. In marine engines we did not hear of frequent breakages of the slide-valve spindles, nor in stationary or portable engines. No doubt a great saving would be effected by a perfect equilibrium slide-valve, and he hoped Mr. Adams had really at last found it.

Mr. Olrick said that, in discussing the paper, it would be as well to pass rather quickly over the first part, which described Mr. Adams's theory of the molecules. It was well known that Dalton was the first who adopted that theory, and it had since been used by many eminent scientific men, because it was convenient for many purposes. Mathematicians, however, entirely denied this theory, for the simple reason, that it assumed that atoms could not be divided, which was shown by a diagram that they could be infinitely. In respect to the other part of the paper, they must all be very much obliged to Mr. Adams for having brought the subject before them. He had started a new era in the knowledge of friction. All Morin's data were based upon cold surfaces. Mr. Adams had given data from hot surfaces on hot surfaces. He (Mr. Olrick) did not agree with Mr. Adams on some points, but still he believed that Mr. Adams had given engineers a great "lift" in the right direction to understand the subject properly. It must be recollected that Morin gave two co-efficients of friction—one for the friction of a surface rubbing against another when in motion; the other was for starting from rest. Mr. Adams had only given the co-efficient when starting from rest, and, unfortunately, had made the mistake of applying that to slide-valves in motion, and so had come to wrong conclusions and results. In Morin's statements, the co-efficients of starting were, as a rule, in the case of cast iron, 40 per cent. higher than those of surfaces in motion; and with other materials they were as much as 60 per cent. higher on an average. On the theory of friction there was a great deal of difference of opinion. Some five years ago, he (Mr. Olrick) had a controversy with the present president, Mr. Colburn, on the subject. He (Mr. Olrick) was of opinion that steam pressure acted in the same manner on steam-tight surfaces rubbing against each other as dead weight. At the time of the controversy, Mr. Colburn was of opinion that steam pressing upon surfaces would go in between the surfaces in contact and press equally upwards and downwards; but he was cautious enough to say "for ordinarily finished surfaces." He (Mr. Olrick) quite agreed with that; but if, instead of using a surface just as it came from the planing machine or the file, they used a surface scraped up, as it was done in the best shops in London, or by Joseph Whitworth, of Manchester, he was perfectly satisfied that steam would

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not go between. Mr. Adams said, in his paper, "The steam says, 'I am master, and I will go between your surfaces, and I will not go out until you can apply a force greater than the area in contact multiplied by the pressure.'" That was correct, because there always was, or ought to be, a much greater surface applied for the steam than for the negative pressure to act upon. It did not, however, apply to all surfaces, for in one instance, in which he was anxious to know whether a slide-valve was steam-tight which had been under steam for three days, he ordered the full steam to be put on, and, although he was inside the cylinder, he did not observe the slightest sign of steam or water coming through, or of any leakage whatever. The steam was most likely to pass through at the narrow strips in the valve. He maintained that, in that case, the slide-valve was perfectly tight. There was no sign, when he examined the vacuum gauge, of any steam passing improperly into the condenser. In practice, the slides ought to be kept well tallowed or greased; for, although it might seem that the grease would no more be able to get in between the surfaces than the steam, still it is, nevertheless, an established fact that it does, and the explanation is, that it is drawn in by capillary attraction, and the presence of it would assist to keep the steam out. As long as the slide was not overloaded, the grease would be retained and the surfaces would not be cut. Mr. Adams next stated that, when there was steam above and below, the valve of the slide would be frictionless. There would be very few practical men who did not know that that statement was incorrect, because a slide was much heavier to move backwards and forwards, when the steam was on, than off. It might apply to surfaces without holes in them, but in practice there was, to his knowledge, no opportunity of using steam on surfaces without holes. Every one knew that, for instance, a large slide-valve, 4 ft. square, could easily be moved forwards and backwards on the surface-plate by one man only at the commencement of the operation of scraping it up to a true surface, but when finished eight or ten labourers would be required to do the same work. This example proved that even atmospheric air only had power enough to press down the slide-valve on the slide-face, and cause the additional friction, which would not take place if the air had passed in between the surfaces and pressed equally upwards and downwards. Another example was the case of hydraulic engines. It had been stated by Mr. Colburn that surfaces would move equally easy whether they were under water pressure or in the open air. He (Mr. Olrick) did not believe that. Mr. James Hendry would no doubt, from his experience with hydraulic machinery, be able to state that a child could move the lever before the water

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pressure was on, but afterwards nearly a man's whole power was necessary to move the same lever when the water was fully on. These were the reasons why he believed that steam pressure on surfaces was equal to dead weight. A little further on in Mr. Adams's paper there was a great discrepancy as to the co-efficients of friction of cast iron for hot dry surfaces. In one place they are given as ranging from ·206 to ·362, but further on Mr. Adams says they are ranging from ·18 to ·21, according to the closeness of the composition. He (Mr. Olrick) wanted to know how he accounted for this. If the circumstances were the same, the co-efficients ought either to be as high in one case as in the other, or there ought to be no co-efficients at all, as it was stated that if a piece were cut out, the steam would go underneath, and the slide would then be frictionless. There was one practical question which had often caused a great deal of difference of opinion and a great deal of controversy; that was whether it paid to spend so much time on slide-valves to get them scraped up in the beautiful manner in which they were generally done by our first-class manufacturers. His (Mr. Olrick's) opinion was about midway between the extremes of opinion on the subject. If the slide-valve and slide were cast, as nearly as practicable, with equal thickness all over, the heat would cause no particular strain on any part of the slide-valve or slide tending to throw them out of truth. If a slide could be scraped up under steam pressure, no doubt it would be better, as it would be nearer the circumstances under which it was to work; but in most cases it would be impracticable to do so, and, at the same time, he had seen many slides which had been scraped up when cold, and yet were perfectly tight. He had during the last three or four years seen several slide-valves taken out of screw colliers made in the North, and they had evidently never been scraped at all, but were as rough as when they came from the planing machine, and had grooves in them ⅛ in. deep. That was the consequence of leaving them in that state, without filing or scraping. Some persons said one surface should be planed the way of the grain of the iron, and the other surface the other way, but it was very difficult to tell which way the grain went, especially in a casting. This plan might do in some cases, but he could mention many in which it did not answer. As regards Mr. Adams's calculations, he (Mr. Olrick) had checked them, and found them arithmetically correct, but still they were incorrect, because the data from which he made his calculations were erroneous. He used throughout his calculations a co-efficient of friction of ·354. He (Mr. Olrick) was certain that that should be ·15, because, according to all experiments made previously, it had been found that when cast iron rubbed against cast iron, without grease, there was a cutting, if

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the co-efficient of friction exceeded ·15. When the same surfaces were well greased, the co-efficient would be reduced to ·07 or ·08. And in the case of eccentrics, the co-efficient used was ·15; but, according to Morin, brass on cast iron had a co-efficient of ·07. The first co-efficient was, therefore, one-third, the second one-half, of what Mr. Adams gave. He (Mr. Olrick) should therefore simply divide the final result which Mr. Adams represented as the amount of power consumed by the friction of the valves and the eccentrics of the North London engine—namely, 129 horse power—by six, which gave about 20 horse power, and engineers would agree that that was much nearer the truth. Mr. D. K. Clark, in his "Railway Machinery," gave the friction of a similar-sized slide-valve as about 20 horse power. If Mr. Adams's calculations were right, and were equally applied to all other parts of the engine, there would be more horse power consumed in friction than the engine would indicate. The strength of a slide-rod must be calculated from the greatest strain that could at any time come on the rod, and this is found in the following manner—viz.: multiply the total pressure by the area of the slide-valve, and that again by the friction co-efficient ·14. This co-efficient should be used for cast iron on cast iron slightly greased or wetted. The result is the weight to be pushed or lifted by the slide-rod. Now, in calculating the diameter of a piston-rod, or a slide-rod, it is necessary to take the crushing force into consideration, being generally less than half that of the tensile force of wrought iron—viz. about 27,000 lb. to the square inch—and allowing a factor of safety of 10, we get $\frac{27,000}{10}=2700$.

Having found the weight to be pushed or lifted by the slide-rod, divide same by 2700, and the result is the area of the slide-rod in square inches. For instance, in a high-pressure engine, having a slide-valve 24 in. by 20 in., the area would be 480 sq. in. With a pressure of 100 lb., that would give 48,000. That multiplied by the co-efficient ·14, and divided by 2700, would give the area of the rod as 2·54 sq. in., equal to a diameter of $1\frac{13}{16}$. Allowing something for wear and tear on the rod, it would be about 2 in. in diameter. According to his (Mr. Olrick's) opinion, Mr. Adams makes here a great mistake in using the average pressure in his calculation instead of the total pressure, which if not used may result in a serious break down.

Mr. William Adams said he had tried the valve under discussion in its present improved state, and he had tried Mr. T. Adams's valves in locomotives in various stages of the invention; they all possessed more or less of the elements of success. The valve, as he (Mr. William Adams) was now using it, he considered a substantial success. It had been working for the last

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five or six months in one of his engines. It so entirely removed the steam pressure on the valve, that it was really easier to reverse the engine when the steam was on than when it was off. That probably arose from the steam giving a lubrication to those parts. Some years ago he had charge of some steam-boat engines which were fitted up with ordinary slides. They did the work tolerably well which they were intended to do, but it afterwards became necessary to increase the pressure on the boiler to more than double, and it was then found that the valve, which had stood very well under the old pressure, was quite inadequate to resist the greater strain put upon it, and many parts doubled up, and the keys came loose. It was found that the only thing to be done was to put in equilibrium valves. That being done, the valve motion stood perfectly well. He believed that generally in marine engines there was packing under the gland or ring. That stood pretty well, except when the steam was rather high—something over 120 lb. to the inch. At that pressure the packing required constant renewing. In Mr. Adams's valve there was no hemp packing or anything of the kind, but it depended for its steam tightness upon the elasticity of the ring, which was turned to a larger diameter than the cavity it went into. It was cut across the edges and sprung into its place with such an amount of force as would give it steam-tightness. He considered that a great improvement made in the valve consisted in adapting what might be called a piston-ring, instead of the solid ring that was formerly used. Before trying the experiments with this valve, he (Mr. William Adams) tried several valves which he had schemed himself, but they all had this solid ring, and the uniform result was an increase in the consumption of fuel, as the steam used to blow through. The circumference of that ring left a very considerable opening for leakage. It was a very nice point to get it of such a diameter as would leave it sufficiently free for working properly, and at the same time make it steam-tight. That had always been a difficulty. If it were made too nice a fit, a little dirt might get in and make it stick fast, and if it were made too slack it would leak. In the present case, if there were any leakage, it came from a very small area indeed. Something had been said about valve spindles. He had found on inquiry that those which had broken had worn and been turned down, and thus reduced considerably from the original diameter. Still, with a pressure of 160 lb., the friction was very great, and he was quite alive to the necessity of applying, if possible, a proper equilibrium valve to locomotive engines. In dealing with very high pressures, engineers had to encounter difficulties which they did not always foresee. He had one engine on which he had tried cast-iron slide-valves, but the cylinders were rather soft, and the

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two metals did not agree. The consequence was, that the working part of the slide wore down very rapidly, and the face of the cylinder had to be lined with a brass facing. It was not a very judicious thing to do, but it worked tolerably well for some time. That engine had recently had a new boiler, and been worked to a high pressure—160 lb. The brass cylinder face, which worked tolerably well before, had been reduced in about two months above ⅛ of an inch in thickness. It was his intention now to put a pair of equilibrium slide valves into that engine, to see how the valve faces would work when the pressure was removed.

Mr. Morris said, that Mr. Adams seemed to say that an enormous quantity of the power of the engine was absorbed by the friction. Had he made any attempt to prove the loss of power, comparing the indicated horse power of the engine with the effective work that was done in its journey?

Mr. C. F. T. Young said, that they must all admit that what engineers chiefly aimed at was to get a certain amount of power out of a machine. Whether a marine, stationary, or locomotive engine, there was considerable power required to move the slide even when cold. If that power could be applied in propulsion, instead of in moving the gearing, or those portions of the engine which enabled it to work, the power would be more usefully employed. He would not say that Mr. Adams's method of effecting this was the best plan that could be made, for there was no finality in engineering; but, so far as he had seen, it was certainly the best. The arrangement was simple, cheap, and well suited to the purpose. In designing an engine, engineers should adopt such means as would secure the power being employed usefully, rather than in tearing the engine to pieces.

Mr. Cargill said that, if he mistook not, the opinion which Mr. Colburn had expressed with regard to the introduction of the steam between the surfaces of the valve was, that the steam did practically insinuate itself. This was simply a question of contact. If the surfaces were in perfect contact there could be no insinuation of the steam; but engineers all knew that, strictly speaking, there was no such thing as absolute contact. If, however, perfect contact were attained in a new valve, so that there was no insinuation of the steam, it would be soon destroyed, unless the two surfaces wore equally; and it was known that cylinders would not wear equally. When the steam got between the surfaces, the real pressure on the valve would not be simply a downward pressure, but the difference between the pressures within and without. Great praise was due to Mr. Adams for his elucidation of the subject of slide-valves.

Mr. Schönheyder said that, as an instance of the very great friction of valves that were not equilibrium valves, he would

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mention the case of a boat tried on the Thames a few years back. The full area of the valve was about 370 sq. in.; the pressure in boiler was 20 lb.; the steam was condensed in the engine, so that the total pressure on the valve might be reckoned at 30 lb. per square inch, assuming some loss between the boiler and the engine, and assuming, of course, that there was not a perfect vacuum. This would give a pressure of 11,100 lb. on the whole area. The levers for starting the engine had a leverage of five to one, and they could with very great difficulty be worked. At one time it was found impossible to start the engine for a few minutes. Four men hung on the lever, and at last a crowbar, with a very short leverage, had to be applied to the valve spindle itself. The force thus exerted in starting was equal to at least 3000 lb., which would give a co-efficient of friction of about one-third. It was afterwards found necessary to put an equilibrium valve to this engine. As to the best way of finishing slide-valves, he had seen instances in which they had been set to work when they had been simply finished on the planing machine. If the two surfaces of a valve were planed in such a way that when they were at work the strokes of the planing on the two surfaces would cross each other, they would, after some time, work themselves to a perfectly true state. He had found it very advisable after a new engine had been at work, if only for half a day, to take the valve out and ease the faces where the hard places were. Those hard places generally occurred at the sides; and he accounted for that by the fact that the temperature of the steam on the steam side must always be greater than the temperature on the exhaust side. He conceived that, with any high pressure, it was impossible to make the valve so that it would remain perfectly true when the heat got to it. With reference to the strength of valve spindles, which had been alluded to by Mr. Olrick, it was no use to construct a valve spindle only just strong enough for average friction. It must be strong enough for the highest amount of friction that could ever come upon it. A co-efficient of friction of ·3 was not too high for a slide-valve.

Mr. Henry Davey said that Mr. Olrick had spoken of the friction of slide-valves under water pressure. He (Mr. Davey) had found that, with a pressure of from 500 lb. to 700 lb. per square inch, the friction was often so great as to cause breakages. He had applied a pair of Mr. Adams's valves, described as being a former stage of the invention, and he had experienced the disadvantages which Mr. Adams had mentioned in his paper. It had occurred to him that a valve might be constructed with a plate of metal at the back of the valve at a slight inclination to the cylinder face, the valve being made at the same angle to

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fit as a wedge between the two surfaces as shown in Plate IV. Fig. 1. The tendency of the steam would be to wedge the valve between the two faces, and the pressure would be represented by AB multiplied by the distance CD, multiplied by the pressure per square inch. In cases where double steam ports are required, instead of a plate at the top of the valve, it should be constructed as shown in the drawing. He had made some experiments with a slide-valve similar in principle to a Cornish double-beat lifting valve, as shown in Fig. 2. The top and bottom areas can be proportioned, so that the steam shall have the same tendency to lift as to press down the valve. A valve so constructed had acted very well for a 10-inch cylinder, but, in cases of larger valves, the unequal expansion of the valve and steam-chest, together with the expense of fitting, had induced him to abandon the idea.

Mr. Thomas Adams, in reply, said that the experiments of Morin had been quoted; the only published authorities on the subject were those of Rennie and Morin. From his own experiments, he could not put the least confidence in General Morin's experiments with reference to the slide-valve. He had not said what weight was applied in any one case. The co-efficient of friction would not be the same at 10 tons as at 20 tons. Unless the weight was specified, the co-efficient could not be relied on. Rennie had entered better into the subject, for he had actually given the weights, and his results were not far wrong. Morin put a block on a plane, and found the point at which it slipped, both dry and under lubricants. He then took a tangent of the angle; that could not represent the co-efficient of friction in any one case unless the molecules partook of the form of a perfect sphere, and just in contact. In such a case the tangent might be made to represent the co-efficient of friction, but in no other case could it do so. The greatest angle of contact of molecules was 30°; the sine and cosine would always represent the leverage of any angle, whatever the position might be. If the sine be taken to represent the force pulling the molecule one way, and the cosine to represent the force pressing downwards, the two forces would be arrived at directly. If the sine and cosine were taken as the two sides of a parallelogram of forces, that would give the result which was wanted. Here the sine was greater than the cosine of 30°. The cosine was greater than it was at 30°, while the sine was reduced. This showed that the co-efficient of friction would be reduced as the molecule came this way, and it was quite possible to show by that means that the co-efficient of friction in motion would be less than the co-efficient in rest. But that entirely depended upon the form of the molecule. With an angle of 45° the sine and cosine were equal, making them equal to the paral-

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lelogram of pressures. The same held good in the case of the resistances which this molecule maintained when this was passing over it. The two forces passed through the point of contact. This proved this to be the angle of stability, and to be the greatest angle. If the sine were made greater than the cosine, the angle would come down, and cutting would take place, as the molecules would cut each other. For taking the co-efficient of friction, the sine and cosine were unity. The radius had nothing whatever to do with it. The radius represented the pull on the valve spindle and the pressure one way; therefore it could not be unity. The co-efficient of ·18 given in the tables was with 20 lb. pressure and soft metal, composed of all pig iron; in the next table the metal used was half Hematite, quarter Gartsherrie, and the remaining quarter was composed of three parts scrap and one part wrought-iron turnings. This gave a better co-efficient of friction ·21. Morin's co-efficients of friction, with respect to the shaft of an eccentric, approached each other pretty nearly, but not when there were great strains, because an eccentric strap was always made very thin. When the force came on the strap it would wrap round, and embrace the shaft in a complete semicircle. A bearing would not do so, being always made to rub not more than two-thirds of the surface. Mr. Jensen had spoken of the breaking of valve spindles, but with a properly made stuffing-box there was no risk of such breakages. No disturbance in a valve could ensue from water in the jacket so long as it did not enter the cylinder, for if water were present the regulator was supposed to be opened, and the water could then go back into the boiler. Mr. Colburn's opinion had been quoted. He (Mr. Adams) had found that all his experiments went to prove that that opinion was quite correct. Mr. Olrick had said that the steam could not enter between the surfaces of the valve. All the co-efficients of friction which he (Mr. Adams) had given were formed with perfectly tight valves. All ordinary valves were steam-tight with the usual pressure upon them, provided that the faces were tolerably true. They would not, however, withstand water; that would go in where steam would not. The only valve, which he had known to be tight with water, was in the *Galatea*, by Penn. The steam would go in between valve surfaces when they were within a balance of 24 per cent.; above that, steam would not enter. He had found that the valve acted as well with the steam on as with it off; that showed him that the steam was acting between the surfaces, and would not allow the valve to come in contact with the cylinder face. Mr. Olrick had stated that the valve was not frictionless; perhaps it was not perfectly so mathematically, but it was practically. Superheated steam had a great deal of friction, and would cut

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like emery, but with saturated steam there was practically no friction. He had made no experiments to ascertain the co-efficient of friction in motion, but he did not believe there was much difference between that and the co-efficient of rest. Morin had found that in many cases the co-efficients in motion and at rest were the same. Morin had found a higher co-efficient of friction when water was used as a lubricant than when the surfaces were dry. He gave ·19 for dry surfaces, ·314 with water as a lubricant. Could that be trusted to? If ·314 was right, the co-efficient in the case of a marine engine would be higher than he (Mr. Adams) had stated. Mr. Olrick said that he thought about 21 horse power was required to work locomotive valves. He (Mr. Adams) must entirely differ from Mr. Olrick in the way he calculates the strength of piston-rods and slide-rods. Everybody knew that the weight multiplied by the co-efficient of friction was the pull upon the spindle. Mr. Davey had asked whether the system could be applied to the double-ported valve. There was no difference whatever, except that care had to be taken which way the vacuum was acting in the double port. Mr. Davey was quite right in what he said about one of the valves. He had given two diagrams of a valve. The first drawing he (Mr. Adams) had not done anything with, but the second one he saw in the *Engineer* in April, 1865, and signed "Davey, Exeter." He had found in that case that there was 19 per cent. excess of negative force pulling the valve from its face in the case of a high-pressure engine, and 39 per cent. in the case of a low pressure. Mr. Davey's valve would not keep the cylinder face, and hence its failure.

The President said Mr. Adams had gone at considerable length into the molecular constitution of matter. That would be a very proper field of inquiry if we could derive any distinct advantage from it; but the great difficulty in such questions was, that, in dealing with them, we were arguing entirely upon the unknown. The most profound philosophers in the world did not pretend that they knew anything positively about the constitution of matter. The subject was a very tempting one, but he did not think that, by any theory as to the form or arrangement of the molecules of bodies, we should come to any true knowledge of the properties or qualities of friction. He understood that Mr. Adams's theory of the cause of friction between two bodies might be represented by one surface studded all over with cannon-balls, cut in halves, this surface being laid upon another studded with corresponding projections. Here the force required to overcome friction was supposed to be really the lifting of the projection of one surface over those of the other. Mr. Adams did not seem to suppose that there was any real friction between

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the molecules themselves. He (the President) believed there was a friction between the molecules of two surfaces of the same metal due to absolute cohesion, this cohesion being to some extent destroyed by the movement of the surfaces. But all theories on these subjects were only speculations. As to steam getting in between two finished surfaces, that was a point on which, perhaps, they had not sufficient material to form a positive opinion, although his own notions about it had always been much the same as Mr. Adams's. His attention was first called to the subject some years ago by Mr. W. S. Hudson, a clever English engineer in the United States. He began to scrape his valve faces very carefully indeed at that time, and to get as fine a surface as he could. This was shortly after the publication of Mr. Whitworth's paper on the subject. He then scraped flat plates, without openings in them, and, on subjecting these to a pressure of steam, it was found that the friction of these surfaces was the same whether the steam was on or off. In all American locomotive engines, the regulator was a sliding valve opened by a rod pulled out by a lever. The spindle of the regulator presented only about an inch and a half end area; but the friction of the valve was so little, that the pressure of the steam upon this area always forced it open if the lever was not screwed up with a thumb-screw. He (the President) believed that the steam always penetrated between the surfaces, but not to the extent which Mr. Olrick supposed. The steam might penetrate the metal itself, for it was known that air would force its way through cast iron, and water would do the same under pressure. Some of the members were familiar with the Corliss engines. There were two in the last Exhibition. They had separate steam valves and separate exhaust valves. As soon as it is requisite to shut off the steam on each stroke, the connexion between the eccentric and the valve was interrupted, and the valve flew back into its place, closing by the action of a moderate weight. At the moment it was to be closed, there was the same pressure in the cylinder that there was on the back of the valve. It was a vibrating valve working in a cylindrical case, but the principle was just the same as though it were a sliding-valve. It could hardly be closed by the weight, did not the steam actually penetrate between the wearing surfaces, thus putting the valve in a state of equilibrium. That went to support what Mr. Adams had said. Mr. Adams had mentioned several of his experiments with different areas of rings at the back of the valve. Those experiments showed substantially what had been shown on the Great Western Railway, in an arrangement once employed there. It was a piston at the back of the valve working in a small cylinder on the bonnet. That

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COEFFICIENT OF FRICTION

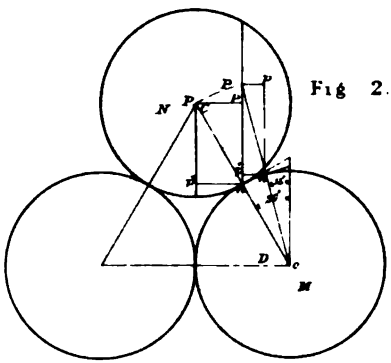

Fig 2.

MOLECULAR FRICTION.

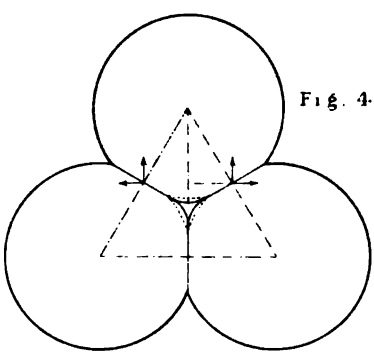

Fig. 4.

Newbery Alexander, Lith 43, Charing Cross, London.

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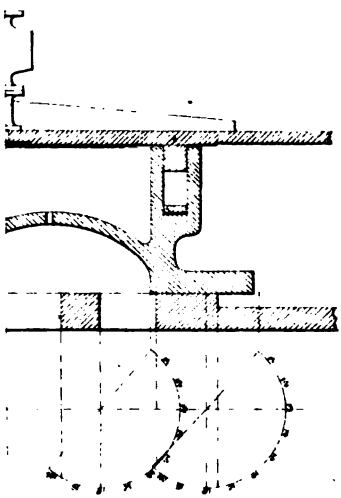
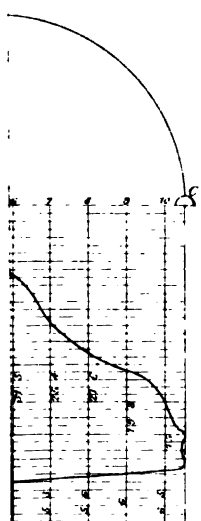
VALVE

1.





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VALVES.

Fig 1.

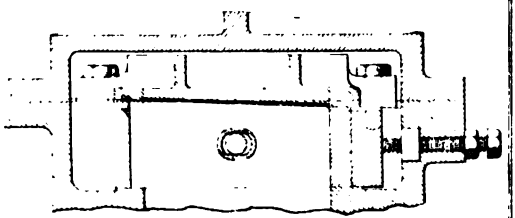
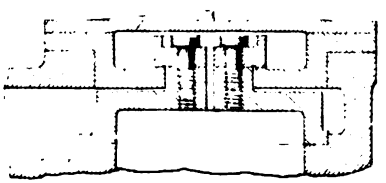


Fig. 2.



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was made too large at first. Mr. Bourne also tried the same contrivance in some engines he made at Greenock or Port Glasgow; and he found that, if the area of the equilibrium piston exceeded the united area of the ports, the valve was lifted off its seat. As to the ratio of friction, it had been pointed out by some of the speakers that Mr. Adams had applied to bodies in motion the co-efficients of friction of bodies at rest; and he (the President) believed there was sufficient evidence to show that the co-efficients would not be the same in both cases. It was supposed that the action of lubricants was to form small rollers between rubbing surfaces, by means of which one surface was enabled to roll over the other. Some years ago, Mr. Hick, of Bolton, placed small cylindrical rollers between the valve faces, but he (the President) could never learn that the plan had been adopted for any length of time in this country; but the same idea was taken up in America some years ago by Mr. Bristol, of Chicago. It was said that this method saved a great deal of friction. There were many engines at work in which no lubricating matter had ever been admitted into the cylinder at all. In those cases the valves could only be lubricated by the steam. If it were not that locomotives sometimes had to run down inclines with steam shut off, their valves would scarcely need any lubrication at all. As to the breaking of valve spindles, it did not seem to have been pointed out in the paper that the plane of resistance of the valve was considerably out of the axis of the spindle, and the spindle was strained with a leverage very different from the strain which was on the piston-rod. He did not know that he ought seriously to go into the calculations made by Mr. Adams with reference to the amount of power required in engines on the Great Northern Railway to work the valves, for he believed that a no more unjustifiable conclusion could be drawn than that one of their large engines consumed 220 horse power in working the valves. Of course a good deal of the estimated friction was in the eccentrics, and Mr. Adams had given all the data for working out the calculations. The remaining 166 horse power would scarcely suffice to overcome the friction of the other parts of the engine at the rate stated in the paper.

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March 5th, 1866.

ZERAH COLBURN, PRESIDENT, IN THE CHAIR.

ON ARCHED ROOFS.

BY CARL VON WESSELY.

THE present paper does not aspire to exhaust the very interesting subject of arched roofs as it stands at present before the profession. Its purpose is only to describe some structures of this kind recently carried out with success, and to make a few comparative remarks upon their main features and merits. In offering the same to this Society, it is the hope of the author to elicit valuable criticism from different quarters, and by a discussion of a subject on the theory and practice of which very little has been published hitherto, to throw more light upon the many important questions connected therewith. It is a desideratum universally felt in the engineering profession to have as complete as possible a collection of the designs and details of important engineering structures: a contribution towards such a collection, however incomplete, may not be thought out of place before a society entirely devoted to the advancement of engineering science.

Arched roofs are the production of the conjoint requirements of beauty and strength. So long as a roof is destined to serve as a mere object of utility, an engineer would spend very little trouble in designing fine outlines and selecting noble proportions. Economy of material and workmanship dictate such plainness of design that, firstly, the engineer shall be able to take out the strains so minutely, as to reduce the sectional area to a minimum; and secondly, that the roof is carried by itself and does not induce any transverse strains in the structure supporting it. The usual triangular principle is adopted in such cases. It is a very different matter when a roof is to be made for an architectural building, for instance a large hall, where it is often the main feature of the structure. Fine outlines and simplicity, two main components of noble appearance, will be required most particularly. No obstructions to the view, as ties, struts, &c., are admissible. Architecture, having been always represented in

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stone, forces its newly acquired material, iron, into the customary shape of the pure arch. A more or less powerful horizontal thrust has now to be resisted, and a certain deficiency in the practicability of minute calculation of strains under unequal loads must be compensated for by the sound judgment of the engineer. Many different arrangements can be embodied in the structure supporting arched roofs, for taking the horizontal thrust, but no rules can be given for it. In each separate instance the arrangement must be adapted to the peculiar nature of the case, and depends for its degree of perfection entirely upon the skilful design of the engineer. A few words on scientific investigations with regard to wrought-iron arched ribs may not be out of place, before beginning the description itself.

The calculation of strains in arched roofs is one of the most difficult mathematical problems in engineering, partly on account of somewhat complicated principles, on which a thorough investigation should be founded, partly on account of a great variety in the position of the different parts of the structure.

Unfortunately there is very little information on this subject to be found in English engineering literature, and not much more in that of other nations. The following is submitted as a means of approximately investigating the stability of wrought-iron arched ribs.

It is well known that the way of ascertaining the stability of a stone arch is to draw the curve of equilibrium, which must remain within the depth of the voussoirs of the arch.

This is not necessary in the case of iron arched ribs, which can be strained by tension as well as compression.

The outer forces, which act upon an arch, are, (1) its own weight; (2) the vertical; (3) the horizontal pressure due to the resistance of the abutments; the latter is transmitted unaltered through the whole of the arch, since there is no other horizontal strain acting upon it but that of the abutments; (4) the pressure of wind and snow.

In every arch there must be somewhere one particular point in which this horizontal strain is not co-existing with any vertical force; therefore, if we cut the arch through this point in two pieces, in either of them the state of equilibrium will be conserved by replacing the action of the other by that horizontal strain.

This point is coincident with the point of action for the resultant of all the vertical forces acting on the whole arch.

Thus in an arch under its permanent load, the section before mentioned will be at the crown; in an arch under both its permanent and unequal loads, it cannot lie in its crown. The curve of equilibrium passes through that section with its vertex.

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The way to find the horizontal strain is as follows:

Given a semicircular arch, loaded on n points, whose horizontal distances from the left hand springing are $x_1\ x_2 \ldots x_n$, with weights $p_1\ p_2 \ldots p_n$ accordingly, and x_m the distance of the vertical section before mentioned, we find $p_1\ x_1 + p_2\ x_2 \ldots + \frac{1}{2}\ p_m\ x_m = \sum_{x_1}^{x_m} p\ x = \mathrm{H}\ y$, where H is the horizontal strain and y the rise of the curve of equilibrium.

This equation $\left(\sum_{x_1}^{x_m} p\ x = \mathrm{H}\ y \right)$ does not determine H or y, but assuming one of them, it ascertains the other.

By taking $y = y^m$ (the height of the neutral fibre in section m) the vertex of the curve is drawn through point C; H is thus determined, and section m is in compression according to H.

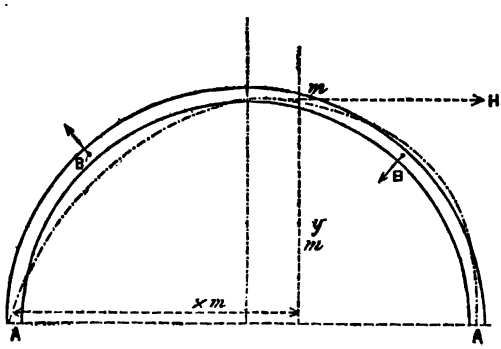
It is quite clear that not all the other points of the curve will in this case fall within the neutral fibre of the arch, but will take the position as shown by the dotted line, though it must go through the supports. This causes a tendency for point B to move in the direction of the arrow, and strains in the flanges at that place will be effected accordingly.

If the flanges of the rib in B should really not be strong enough to withstand this strain, there is no necessity yet that they should break, but the case will be as follows:

$y^m{}_1 = y$ is assumed, so that the curve of equilibrium passes through B, and renders this point to be simply in compression.

H is determined by the equation $\mathrm{H}_1 = \dfrac{\sum_{x_1}^{x_m} px}{y^m{}_1}$ and acts on a lever $= y\ m_1$, or in regard to section m on a lever $y\ m_1 - y\ m$, and will effect a compression in the upper flange and a tension in the lower one at this place.

Fig. 1.



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Thus the fact that the section at B is in mere compression is conditional, and depends entirely on the presence of the said strains in the flanges at section *m*.

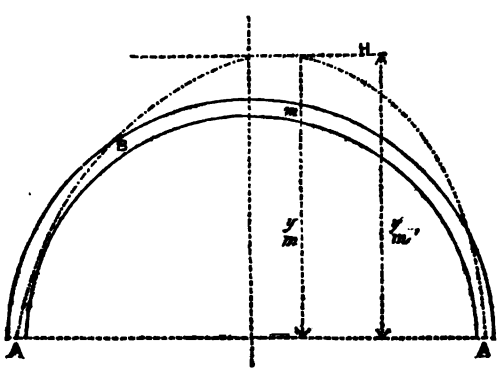
In respect to these considerations, it is certain that stability and rigidity of an iron arched rib can be fulfilled by different arrangements.

Although it appears strange at first sight that in an arch, of which the architectural outlines are given, there should be no restriction in assuming the rise of the curve of equilibrium, according to which the different sectional areas could be determined, and that nevertheless the stability of the structure can be effected, this will become obvious from the following example:

Given an elliptical arch, in which the different areas in flanges, &c., have to be determined, the distances of the points where the loads act and the loads are determined.

Then the equation $\Sigma px = Hy$ can be formed, by which it can be seen that H, the horizontal strain, might be taken *ad libitum*, and that y will then be ascertained according to the equation. For instance, y may be taken equal to a^1, which is greater than the rise of the arch, the vertex of the curve will be in C^1, and its branches will go through the points of support, as shown in sketch.

Fig. 2.



H^1 is determined by putting a^1 for y in the equation.

The position of this curve leads to the remark, that in the crown, besides the horizontal strain H_1, which is transmitted through the structure and taken by the abutments, there will be a certain tension in the lower and a compression in the upper flange, due to H_1 acting on the lever CC ; and that, following

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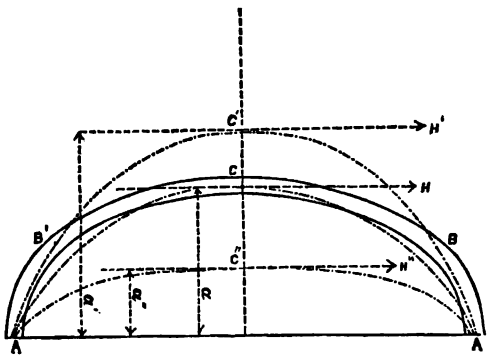
the line of the curve from C_1 towards A_1 or A, there is a point B_1 or B on each side, where the curve of equilibrium intersects the neutral fibre of the arch, and where only compression exists.

The segment between B_1 and B therefore acts as a girder, while the joints at these points could safely be replaced by hinges as long as the load is equally distributed. The abutments will in this case react with a horizontal strain equal to H_1.

Fig. 3.



Now, instead of the abutments, a tie may be supposed between A_1 and A, and a screw in it, to effect any required horizontal strain on these points, and it may be arranged so that this horizontal strain is $= H''$. By putting this H'' into the equation, the calculation gives $y = a''$, which is smaller than the rise of the arch. A_1 C'' A is now the curve of equilibrium.

The horizontal strain H'' is transmitted through the crown unaltered; but, besides this, there exists at the crown tension in the upper and compression in the lower flange, due to H'' and the lever CC'', on which it acts. According to the curve assumed in this case, the whole of the arch will act as a girder under forces acting upwards, and the dimensions of the flanges and diagonals have to be determined accordingly.

No doubt, by means of the supposed screw, a horizontal strain, H, can be applied to the arch, so that the corresponding y becomes equal to the rise of the arch a, in which the entire section at the crown is in compression due to the force H. In other words, by means of a tie and a screw in it, the curve of equilibrium can be forced to pass through the crown, or through any other point in the vertical C^1 C'', and if the material is dis-

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tributed in the structure according to a certain curve of equilibrium, it will enable the abutments to bear the horizontal strain belonging to this curve.

On the other hand, this does not require that a wrought-iron arched rib of a certain shape must have abutments of a certain strength, there being even a chance for the stability of an arch without any abutment or tie. The only consequence of this is, that the rise of the curve of equilibrium becomes ∞, and the horizontal strain by the equation becomes 0.

The crown of the arch will, therefore, be strained as if it were the centre of a straight girder of the length $A A^1$. Now the question arises, which curve of equilibrium, among so many which do not exclude a chance of constructing the arch, will be that one according to which the least quantity of material is required?

Although the solution of this question with mathematical accuracy is a matter of almost impracticable complexity, the following consideration leads to a sufficiently practical result: namely, it can be proved by simple calculation, and by many instances of practical engineering, that a certain load distributed over a given space can be supported in a more profitable way by an arch, in which only compression prevails, and which rests between abutments, than by a straight girder. Therefore it is more profitable to arrange the material in a structure so that it is strained only by compression, than to have compression and tension coexisting in every part of the structure.

From this truth a rule can be derived to lay the curve of equilibrium so that its points may be as close as possible to those of the neutral fibre.

The further calculation of strains in the different parts of the structure (flanges and diagonals) can be dealt with by starting at an intersection of the curve of equilibrium with the neutral fibre, where the strain is known from the curve, and continuing by proper combination of this strain with the vertical loads.

Main Arched Roof of the Dublin Exhibition Palace and Winter Garden.—(Plate 1.)

The area devoted to the portion of the exhibition covered by this roof is 218 ft. 10 in. × 50 ft. 6 in. The space occupied by the Winter Garden, which is covered by a similar kind of roof, is 353 ft. 6 in. × 50 ft. 6 in., having a transept 33 ft. 8 in. wide and 50 ft. 6 in. long. These two areas are divided respectively into 13 and 21 bays of 16 ft. 10 in., as shown in the figure. It is proposed to consider the various details together, that is to say, the roof proper comprising the principals, purlins and

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covering, and the supporting structure, with the arrangements for taking the horizontal thrust.

The outline of the arched rib principal is semicircular, the radius of the intrados being 20 ft. 6½ in., and the extrados 28 ft. 1½ in. The rib is thus at its crown 1 ft. 6 in., and at its springing 2 ft. 8 in. deep. It consists of a bottom and top flange each of 2 L irons 3½ in. × 2½ in. × ⅜ in. throughout its length connected together by diagonal bars. The four diagonals next to the crown of the rib are 2⅛ in. × $\frac{7}{16}$ in., the next three are 2¾ in. × ½ in., then follow three of 3 in. × ½ in., and the last three are 3¼ in. × $\frac{9}{16}$ in., the rivets for connecting the diagonals to the flanges being ¾, ⅞, and 1 in. in diameter according to the strength of the diagonals. At their intersections the diagonals are connected by ¾ in. rivets. At each point where the dimensions of the diagonals vary, the purlins are fixed. There are therefore three purlins on each side, exclusive of the ridge purlin at the top. The purlins are of cast iron, and their construction is well adapted for securing water-tight joints where the covering is fixed to them. They are cast in lengths of 16 ft. 10 in., 9¾ in. in height, and ⅜ in. thick, the bottom flange being ½ in. thick. The web of the purlins is ornamentally perforated, the perforations being glazed, and the joints of the purlins chipped. For connecting the purlin firmly to the rib, and to give it a certain amount of lateral stiffness, two ornamental brackets are fixed by four bolts, 1 in. diameter, to the rib, so that one end appears to support the purlin to which it is well bolted, and the part fixed to the rib being ½ in. in thickness acts as a stiff strut.

Under each of these brackets of ⅜ in. metal an ornamental finial is fixed to the soffit of the rib, on which a 7 ft. × ⅞ in. board is fastened to cover the open space between L irons. The two upper bolts of those connecting brackets to ribs serve for fixing the wind ties, the ends of which are flattened down in the usual way, and have right and left-hand screws for adjustment.

The roof of the Exhibition Palace is covered with Italian zinc and glass. The zinc is No. 14 gauge on rolls 3 in. × 1½ in. about 1 ft. 2¾ in. apart.

The Winter Garden is covered with glass on sash bars 2¼ in., and 2⅛ in. × 1½ in., about 1 ft. 2¾ in. apart. The glass or zinc overhangs centre of top flange of purlin 4½ in.

The ventilation in this roof is effected by a novel arrangement at the top. The ribs carry in their centre cast-iron standards, which are connected at the top on each side by one L iron 3½ in. × 3½ in. × ½ in., for supporting the covering and giving the standards lateral stability. The space between these two angle irons is used for ventilation, and can be opened or shut by means of a valve consisting of a piece of convex sheet iron fixed to a

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spindle running along the roof and having a bearing in each of the cast-iron standards.

At certain places pulleys and balance weights are fastened to the spindle, from which a cord goes down to the floor of the building. By means of this cord the spindle and valve can be turned, and the opening or shutting of the ventilator controlled.

The whole apparatus is covered by a piece of corrugated zinc forming the ridge, and fixed on small cast-iron supports.

The main ribs weigh each 2¼ tons. The weight of purlins in one bay is 1 ton 1 cwt. 21 lb., and the weight of brackets for one bay is 5 cwt. 42 lb. The entire weight of wrought and cast iron in one bay, exclusive of covering, is 3 tons 14 cwt. Each of the ribs is supported by a cast-iron column, 45 ft. high from floor level, in three lengths. There are other series of columns, 32 ft. high, in two lengths, 16 ft. 10 in. apart from the columns supporting the main roof, thus forming squares of 16 ft. 10 in. The first tier columns carry at a height of 15 ft. cast-iron girders 2 ft. deep, with ends widened out to brackets supporting the flooring of the gallery. At a height of 32 ft. they carry a cast-iron arched roof of 13 ft. 5 in. clear span. The inner columns support the ribs by brackets, which are cast on the clerestory columns, the inner curve of which completes the semicircle of 24 ft. 6½ in. radius. The base of the rib is simply bolted to the top of springers with six 1 in. bolts.

The horizontal thrust is transmitted by this bracket, and a flying buttress fixed to the column. The cast-iron principal of small roof is fixed to the inner and outer columns by bolts.

This thrust tends to overthrow both columns outwards from the top, but they are strongly connected under floor level by a cast-iron girder 1 ft. 6 in. deep, and thus form, with the upper gallery girder and the arched roof, a strong frame. By having the connexions made sufficiently strong, and the columns increased in thickness at the required parts to enable them to bear the transverse strain, this frame becomes perfectly rigid, and takes the horizontal thrust without the aid of diagonal bracing.

The columns are cast in two lengths, one portion extending to the top of the gallery girder, and the other to the lower and upper gutters in the first and second tiers. They are connected by four 1 in. bolts, two of which fasten the tie rods for the diagonal truss of gallery flooring directly to the column. The greater part of the permanent and moving load of the gallery is thus brought directly on to the columns, and the gallery girder is left to take the thrust of the ribs.

The capital of each column supporting springing of cast-iron side roof is formed by brackets projecting from each side, leaving

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the column itself to pass through. The water is carried off from the gutters of the main roof by the columns. The two sides acting as flanges in relation to the transverse strain arising from horizontal thrust are $\frac{7}{8}$ in. thick, the remaining two sides are $\frac{5}{8}$ in. thick. The longitudinal girders of the gallery are connected to the columns by dovetails cast on the columns at each end, fitting into corresponding grooves cast in the ends of columns, allowing $\frac{1}{4}$ in. space, which is run with lead.

The bottom girders have $5\frac{5}{8}$ sq. in. sectional area in the top and bottom flanges, and are widened out at both ends so as to form a sort of square box, to which the bases of the columns are attached by four $1\frac{1}{2}$ in. bolts. The columns with boxes and girders rest on foundations of concrete. The flying buttress is composed of several pieces shown in the detail drawings, the joints being applied so as to secure correct action and good workmanship. The weight of ironwork in one bay of supporting structure is 7 tons 18 cwt.

Arched Roof of the Derby Market Hall.
(Plates 2 and 3.)

The area covered by this roof is a rectangle 192 ft. long and 86 ft. 6 in. wide. It is divided into eight bays of 24 ft. each. The roof is hipped at both ends, and therefore there are only five ordinary principals of 81 ft. 5 in. clear span. The principals consist of wrought-iron arched ribs, the inner and outer curves being true circles struck from the same centre, with radii of 43 ft. 9 in. and 41 ft. 5 in. respectively, the springing of rib being 7 ft. 6 in. above centre. The height of rib at crown is 62 ft. 10 in. above the floor level. The wrought-iron rib is of the same depth throughout, and consists of $\frac{5}{16}$ in. web, and top and bottom flanges each of two L irons $3\frac{1}{2} \times 3\frac{1}{2} \times \frac{7}{16}$.

At every alternate supporting place of the purlins the web is joined by means of a joint plate 1 ft. 9 in. × $10\frac{1}{2}$ in., $\frac{1}{2}$ in. thick, which plate is also riveted on to the web at the other purlins as a strengthening plate. Angle irons extend always over two lengths of web. The web is ornamented in an original way. A neat design of holes is punched out of the solid plate, leaving the material intact where it acts in a similar manner to diagonals. As holes show much better than mere lines or raised ornaments, the effect is much more powerful; besides, it seems the only right way of ornamenting a plate girder, because the main construction lines, adapted to certain scientific laws, are not only left intact, but even brought out to a greater extent. Ornamentation by casings and ornaments stuck on may be sometimes really required, but if the real working structure can be made in itself

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good looking, its merit is far greater. These holes (the larger ones, about 6 in. in diameter) were punched out by a simple screw press, with long levers and heavy weights attached to them. When brought once into the swing, the mere momentum suffices to drive the punch through the plate, which is $\frac{5}{16}$ in. thick. The base of rib is horizontal, 2 ft. long, while the top flange is 2 ft. 5 in. above, carried vertically down. It is fixed by eight 1 in. bolts, on each side of the web, to the supporting cast-iron column, the angle irons of the bottom flange being carried round horizontally for that purpose. Riveting is done throughout with $\frac{3}{4}$ in. rivets, about 4 in. pitch. A board $8\frac{3}{4}$ in. wide by 1 in. is fixed to soffit of rib for mere appearance. The rib carries wrought-iron lattice purlins, at intervals of 6 ft. 9 in. On each side of such purlin a cast-iron strut is fixed to rib and purlin by six $\frac{3}{4}$ in. bolts. By this connexion, the projecting of the purlins beyond the ribs is prevented.

The purlins, which are 23 ft. 10 in. long and 1 ft. 6 in. deep, are radial, and are connected to the main ribs by means of the cast-iron end struts of $\frac{3}{8}$ in. metal by two $\frac{3}{4}$ in. bolts. They consist of a simple truss, the top and bottom flange of which are each formed by two L irons $3 \times 3 \times \frac{3}{8}$ in. The top flange is also connected by two $\frac{3}{4}$ in. bolts to top flange of main rib. Cast-iron struts, 3 ft. pitch, and flat bar diagonal bracing $2\frac{1}{2}$ in. wide, increasing from $\frac{1}{4}$ in. to $\frac{3}{8}$ in., and $\frac{1}{2}$ in. in thickness, connect the flanges of the truss by $\frac{3}{4}$ in. bolts serving as pins for diagonals. Wooden diagonals are also used for giving the appearance of a complete diagonal truss. The purlins support at each strut a wood rafter 6 in. + $\frac{3}{4}$ in. Each alternate strut is so enlarged as to form brackets connected to the wood rafters by $\frac{5}{8}$ in. bolts, which are employed to keep the purlins in their radiating position. The other struts are brought out at the top to mere lugs fixed to rafter by $\frac{3}{8}$ in. coach screws.

On the top of the main ribs a piece of wood $5\frac{1}{2}$ in. $\times$ 3 in. is fixed for nailing the 1 in. boarding thereto.

The 1 in. boarding is covered by Italian zinc near the crown, and at the lower part by slates. A portion of the roof is glazed.

The ends of the roof, it being hipped, are formed by ribs which are in general constructed like the ordinary ones, but stronger in cross section.

One ordinary rib weighs $5\frac{1}{4}$ tons, weight of purlins, standards, &c., for one bay, $9\frac{1}{2}$ tons.

The ironwork for one bay of roof weighs $14\frac{3}{4}$ tons.

Each rib is supported by a cast-iron column, 23 ft. high from floor level to bottom of gutter, of an octagon section, and $1\frac{1}{2}$ in. thickness of metal. The base is also octagon, 2 ft. 10 in. high, and at the bottom of 2 ft. inscribed diameter. At a height of

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19 ft. 7 in. from floor level it widens out into an octagon capital of 2 ft. 9 in. inscribed diameter at the top. The base is plain. The top is a little ornamented by raised leaves. Above that the column widens out into a kind of flat box, 4 ft. 2 in. high, with a bracket in front supporting the horizontal plate to which the L irons of base of columns are bolted. The horizontal plate extends over the middle of the continued column, leaving on each side of bracket oblong openings for receiving outlets of gutters; the column changes above this horizontal plate into a vertical piece of H section, 1 ft. × 10½ in. × 7¾ in. × 1¼ in., 4 ft. × 4 in. high. The vertical part of the base of rib is bolted, as already mentioned, to the inner flange, 10½ in. wide. The bracket in front, being merely a web, is hidden by a casing, appearing as an ornamental bracket, of the same thickness as the flat box forming part of column, which is in elevation shaped like the two brackets supporting the outlets of gutter on each side of column. The gutter joins the column by a semi-elliptical arch forming the outlet. The casing is here required for the sake of appearance and for saving a core. To the back of upper part of column (supporting outlets and the upper flange of the H iron), a frame 11 ft. 6 in. long is fixed by six 1 in. bolts. It consists of an arch of 5 ft. 1 in. radius of bottom outline, with a pretty filling-in ornament, and on the top a square frame 2 ft. 6 in. deep. All the main flanges are 8 in. wide, ¾ in. thick, only the upper flange of frame 1 ft. wide × ¾ in., the web being ½ in. thick. The other end of the frame is suitably provided with a vertical flange and a lug at the bottom, for resting on the wall, being besides bolted to it by four 1 in. bolts.

This frame would apparently transmit the horizontal thrust to the walls enclosing the hall, but that is not the case. The horizontal thrust is in this roof taken by a very peculiar arrangement. On the top of the frames just described, on each end strong boxes are cast on, each of which contains a pin dropped into it from above. These pins connect the ends of diagonal bracing rods, with eyes on one end and key adjustment at the other. Along the outer boxes a wrought-iron flange runs throughout the length of the building, decreasing towards the ends in strength, the diagonals increasing towards the ends. This flange, consisting of four plates, 1 ft. × 1½ in., and two L irons, 3 ft. × 3 ft. × ½ in. in centre, is connected by the pins to the diagonals. On the other hand, the gutter acts as the other flange of this horizontal girder, and is made sufficiently strong, being cast 1⅜ in. thick. The single lengths of gutters are connected together by means of eight 2 in. bolts, being equal in sectional area to the strength of the gutter, of course piercing the web of I-shaped part of column. The gutter, being of cast iron,

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and sometimes exposed to tensile strains, requires, therefore, the above-mentioned area. There are eight diagonals, one for each bay; the dimensions of the rods increase from the centre towards the ends. The diagonals having to sustain just the same as the flanges, contrary strains must be always of the same sections as them, because they can only act as the ties. At the hip of the roof only simple ties are required as diagonals.

The roof offering in its longitudinal direction a very great resistance, renders it unnecessary to provide for an extra horizontal thrust arising from wind pressure, &c.

The gutter, being 1 ft. × 5½ in. deep, 1 ft. wide, and 23 ft. × 4 in. long, 1⅜ in. thick, has in distances of 3 ft. small shoes cast on, which receive the ends of the intermediate rafters 6 in. × 3 in. The rafters are placed across the 12 ft. corridor at a proper slope, laid with 1 in. boarding, and covered, like the large roof, with slates. The other ends of these rafters rest in shoes on the wall surrounding the hall. The gutter is covered by a snow grating, which is 1 ft. × 3 in. wide, and cast in lengths of 6 ft. It rests on small supports fixed by two ⅝ in. bolts to cross pieces cast on the gutter at every second pair of shoes, and serving as distance pieces in the casting, while it cools and prevents it from warping into awkward shapes. These distance pieces must always be made with a top flange, otherwise the other parts of castings prove stronger in shrinking, and tear it in the middle. The rain water is carried sideways by the bracket-shaped outlets of gutters into the column, and carried off by same to the drain pipes. The cast and wrought ironwork of one bay of roof weighs 14¾ tons. The cast and wrought ironwork of one bay of supporting structure weighs 17¾ tons.

Sydenham Crystal Palace Roof.—(Plates 4 and 5.)

There are two roofs of similar construction, but of different span. The principals are, in both roofs, arranged in pairs, being 24 ft. apart in each pair, but the pairs leaving a clear space of 72 ft. between them. The 120 ft. span roof is to be described first, the alterations of dimensions in the 72 ft. one are to be given afterwards, the details being alike in regard to general arrangement.

The principal of this roof is very peculiar in its construction. It is an arch of such a depth, that it carries partly as a girder, throwing upon its supporting structure a comparatively small horizontal thrust. The outer and inner outline of the arch is a perfect semicircle, struck from the same centre; the rib has therefore an equal depth of 8 ft. throughout, the inner radius being 52 ft., the outer one 60 ft. The rib consists of a bottom

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and top flange, each consisting of two L irons 6 in. × 3½ in. and a ¼ in. plate 10 in. wide, having an available sectional area of 9⅞ sq. in. These flanges are throughout the length of rib of equal cross section, and are connected together by a double lattice-work, made of flat diagonal bars. Each side of the rib is divided into eleven equal parts, between its springing and its centre. Each of these parts contains two diagonals one above the other, and struts radiating to the centre; one of the struts being a cast-iron distance strut carrying purlins and connecting them to main rib; the other is a wrought-iron strut made of two channel irons 4 in. × 1½ in. × ¼ in., having two distance pieces riveted between them. The joints in 6 in. × 3 in. L irons are made alternately at intervals of about 14 ft., proper distance pieces filling out the 3⅝ in. space between L irons, its ¾ in. rivets act only with single shearing area. At intervals of about 1 ft. 9 in., distance pieces are put between L irons, and fixed also by ¾ in. rivets, the same as in wrought-iron struts. The diagonal bars are throughout 4 in. wide, ⅜ in. thick, with an available sectional area of 1·2 sq. in. running always through two diagonals, and are not straight. But they are, for the sake of architectural appearance, so arranged that they cross exactly in the middle of rib, and in one-fourth of its depth from its outer and inner outline. They are connected at intersections by a ¾ in. rivet. A round ornamental knob, made in two halves, being connected together by three ⅜ in. tap screws, covers this joint. The ends of diagonals and wrought-iron struts are connected with the L irons by a 1⅛ in. bolt.

The cast-iron distance struts are shaped according to the wrought-iron structure which they have to strengthen, and according to the cast-iron end pieces of purlins which are bolted to them by either six or four ⅞ in. bolts, as they belong to the 6 ft. or 3 ft. deep purlins.

The strut has accordingly a cross section of 7 sq. in. sectional area, its ⅜ in. web is widened out to a pocket for letting the diagonals through, intersecting at this point. The web at top and bottom of strut is brought out to two lugs, which fit with a washer between the two angle irons, and are each bolted to same by one 1½ in. bolt. Proper bosses are cast on to the web for eight ½ in. bolts connecting purlins to same. Underneath these struts, ornamental pendants of $\frac{9}{16}$ in. metal are screwed on to soffit of rib by four ½ in. bolts. There are two kinds of purlins, one kind being 24 ft. long, 6 ft. deep, and the other 72 ft. long, and 3 ft. deep. The first serve for bracing two ribs of one pair together; the others act as pure purlins between each pair of ribs, that is, they are only to support the intermediate rafters.

The 6 ft. deep purlins consist of a top and bottom flange of

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two L irons, 3 in. × 2 in. × $\frac{1}{4}$ in., of 2 sq. in. available sectional area; they are connected by wrought-iron struts and double lattice-work. Besides carrying intermediate rafters, they serve as bracing of main ribs for giving them lateral stiffness. The struts are 8 ft. apart, and consist of two T irons, 2 in. × 2 in. × $\frac{1}{4}$ in., with $1\frac{1}{2}$ in. available sectional area, having between them in all cases two diagonals, one above the other, similar to the lattice-work in main rib. The diagonals are flat bars, 3 in. wide, $\frac{5}{16}$ in. thick; they are straight, and run always through two divisions of 8 ft. At their ends proper cast-iron distance struts are fastened to L irons by one $1\frac{1}{8}$ in. bolt, the web is again properly widened out to a pocket for receiving the ends of two diagonal bars, which are riveted to the casting by one $\frac{3}{4}$ in. rivet. The 3 ft. deep purlins serve only for carrying the intermediate ribs; they consist of a top flange of two L irons, 4 in. × 2 in. × $\frac{1}{4}$ in. 2·44 available sectional area in centre, and a bottom flange of two flat bars being at the end $4\frac{1}{2}$ in. × $\frac{3}{8}$ in., in centre $4\frac{1}{2}$ in. × $\frac{3}{4}$ in., with 4·68 sq. in. available sectional area. These flanges are connected by vertical struts 8 ft. apart, and diagonal tie bars decreasing in the three diagonals next to end, from $\frac{11}{16}$ in. thickness to $\frac{1}{2}$ in. to $\frac{5}{16}$ in. to $\frac{1}{4}$ in. They are respectively fixed to top and bottom flanges by a $1\frac{1}{4}$ in., $1\frac{1}{8}$ in., 1 in., and $\frac{7}{8}$ in. bolt. All bars are 4 in. wide (the struts are of cast iron of a (X) cross section, 2 in. × 2 in. × $\frac{3}{8}$ in.), diagonals of wood are put across the diagonal tie bars, 4 in. wide, $\frac{1}{4}$ in. thick, fastened by $\frac{3}{8}$ in. bolts.

Both purlins carry above each strut an intermediate rafter, having the same outline as the main rib. It is made of a $\frac{1}{8}$ in. web plate 1 ft. high, in length about 8 ft. 5 in., with a top and bottom flange consisting of two L irons 2 in. × 2 in. × $\frac{1}{4}$ in., in length about 16 ft. 10 in., with $1\frac{1}{2}$ sq. in. available sectional area. A special arrangement is made for bracing purlins sideways to these intermediate ribs. The purlins at the bottom end of their vertical struts are suspended by two rods to points of the intermediate ribs, being just in the middle of two bearings or purlins. For that purpose, a cast-iron shoe is fixed to the bottom L irons of rafter at those points by four $\frac{1}{2}$ in. bolts of a proper shape, to receive the ends of the hanging rods, $\frac{5}{8}$ in. in diameter. The other ends are widened out to an eye, which is connected to the bottom flanges of the 6 ft. or 3 ft. purlins by the bolts, fixing end of vertical strut to the same. The details of this connexion are for both purlins the same, except the altered angle of the hanging rods. Next to each of the cast-iron end struts of purlins a kind of pocket is riveted by eight $\frac{3}{4}$ in. rivets, consisting of two $\frac{5}{8}$ in. plates, with two $1\frac{1}{4}$ in. thick distance pieces between them, for receiving the ends of wind ties. These are flattened out to eyes, and fixed by an $1\frac{1}{2}$ in. bolt. The wind ties are, through-

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out, round rods of $1\frac{3}{4}$ in. diameter, and form the diagonal bracing between main ribs. At the point where they cross each other they are connected by a ring, to which each end of the four is screwed in the usual way. The ring is, in this case, of cast iron, and has a sectional area of $9\frac{5}{8}$ sq. in., strengthened by proper bosses round the bolt holes, and, besides, by two wrought-iron rings of 1 in. sectional area, put on while red hot. This connexion serves for bringing strain on to these diagonal bracing rods.

The covering of this roof is entirely of glass, on the "ridge and furrow" principle. The main and intermediate ribs carry wrought-iron gutters, 9 in. wide at the top, 7 in. at bottom, 4 in. deep. They are riveted to top L irons of ribs with $\frac{1}{2}$ in. bolts, about 9 in. apart alternately, and to intermediate main ribs with $\frac{3}{8}$ in. bolts in the same way. To the edge of this gutter an L iron $1\frac{1}{2}$ in. × $1\frac{1}{2}$ in. × $\frac{3}{16}$ in. is riveted, and to this a piece of wood $1\frac{1}{4}$ in. × $2\frac{1}{4}$ in. is fixed by $\frac{3}{8}$ in. screws, about 6 in. apart. Into this piece of wood the ends of the sash bars are let in about 1 ft. apart, the top being fixed to the ridge. This miniature roof runs right along the whole rib, from the main gutter up to lower standards of ventilator, and is hipped at its ends. The main ribs, as well as intermediate ones, carry at their crown, over the cast-iron distance strut next to centre, a louvre standard of cast iron 5 ft. $10\frac{1}{2}$ in. high of H cross section. The sides are filled in with wood, to which the louvre plates are fixed.

The ventilator is covered, as the other parts of roof, by a number of similar small hipped roofs, formed by mere slanting sash bars, having in this case only wooden gutters, each supported by the standard in centre of each rib. The outer standards of ventilator are held up by a diagonal bracing running from one to the other, and consisting of $\frac{1}{4}$ in. round rods, which pass through a slotted hole, spaced out in the middle one. A wrought-iron gutter runs along the base of the outer standards, supported by wood boarding, for conducting the water, which drops down from the ventilator covering to the gutters on top ribs. The main rib weighs 10 tons. The purlins, which are 6 ft. deep, weigh each 12 cwt.; those 3 ft. deep weigh each 1 ton 4 cwt. The total ironwork in one bay of 86 ft. weighs 61 tons 3 cwt. Each of the main ribs is supported by two columns, 8 ft. apart, so that each of the flanges starts over one of the columns. This is effected by means of a cast-iron square frame, 8 ft. 8 in. wide and 8 ft. high, bolted to top of each column by four 1 in. bolts, and also by four 1 in. bolts to top of girder, connecting top of columns. It consists of two pieces of the same section as the columns, connected by a $\frac{3}{4}$ in. web with a large circular hole taken out in the middle, and smaller ones in the corners. Proper flanges are cast

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on the top corners of it, to which each of the flanges is bolted by six $1\frac{1}{8}$ in. bolts, by means of a strong bracket. The cross sections of this frame, through the weakest part of the columns, has $25\frac{3}{4}$ in. sectional area, the octagon columns being 8 in. in diameter and 1 in. thick, the web and its flanges $\frac{3}{4}$ in. thick. The parts of frame acting as bracing to the angles have 9 in. sectional area. Appropriate pockets for receiving the ends of the diagonals are constructed in the upper end of web, the outline of which is shaped like that of the cast-iron distance struts. The two diagonals in the middle are fixed to it by one $1\frac{1}{2}$ in. bolt, and the diagonals at the springing of flanges by one 1 in. bolt each. On top of the outer column of frame, lugs are provided for fixing brackets of $6\frac{1}{4}$ in. inner width under the water outlets of main gutter by four 2 in. bolts, with 1 ft. 2 in. × 5 in. waterway. The main gutter running along the whole roof is, on the average, 1 ft. 9 in. wide and 11 in. high. It is cast in lengths of 7 ft. $11\frac{1}{2}$ in., $\frac{7}{16}$ in. thick, the joints being made by eleven $\frac{3}{8}$ in. bolts. The intermediate ribs are supported by cast-iron standards 8 ft. high, resting on one of the cast-iron girders 3 ft. deep and 23 ft. $3\frac{1}{4}$ in. long, which serve in the whole building as bracing and floor, and also carry girders between columns 24 ft. apart. Such girders also brace the columns lengthways under the flanges of main rib. The before-mentioned standards have the section of half a column of 9 in. diameter, are of $\frac{5}{8}$ in. metal, and widened out at the top to a bracket, on which the base of intermediate rib is bolted by six $\frac{1}{2}$ in. bolts. The lowest of the purlins connected to the top of the frame for supporting main rib is also connected by four $\frac{1}{2}$ in. bolts to this bracket, and proper lugs are cast on the top of standard for fixing a bracket, by four $\frac{3}{4}$ in. bolts supporting main gutter at each 8 ft. The horizontal thrust of the main ribs is transmitted by the cast-iron frame to the system of columns, which are connected by cast-iron girders as described before, and well braced by diagonals fixed to ends of girders by means of keys.

At the intersection of vertical diagonals, a similar adjusting connexion with a ring and screws, as that for wind ties, is applied, the whole being hidden by an ornamental joint cover. The entire supporting structure up to the frame is very rigid, and besides being heavily loaded by bearing girders below floor level, and on one side a fireproof flooring of brick arches, and also on the other side cast-iron girders fastened to brick foundations, can take easily the thrust arising more from wind pressure than from the weight of the roof, this being taken partly by the rib itself, which is of a very great depth. The rain water is carried off in the usual way by the hollow columns.

The smaller roof is very similar to the larger one, as already

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stated; the dimensions only of the details being altered. The principals are arranged in pairs, being 24 ft. apart, each pair having a clear space of 72 ft. between. The rib of principal has an equal depth throughout of 8 ft., its outer and inner semi-circular outline being struck from the same centre respectively, with a radius of 36 ft. and 28 ft. The top and bottom flanges are connected by flat bar diagonals and wrought and cast iron struts. The flanges consist of two L irons, 4 in. × 4 in. × $\frac{1}{2}$ in., having an available sectional area of 6·36 in. The diagonals are throughout flat bars, 4 in. wide by $\frac{5}{16}$ in., having an available sectional area of 1 in. The vertical wrought-iron struts are of channel irons, 4 in. × $1\frac{1}{2}$ in. × $\frac{1}{4}$ in., with an available sectional area of 1·37 in. The ends of these struts and diagonals are connected by one 1 in. bolts to the flanges. The L irons are jointed in lengths of about 25 ft. alternately. The arrangement of lattice-work is the same as in the large roof. Pendants are fixed underneath them to soffit of rib in the same way. There are also two kinds of purlins—6 ft. deep, nearly 24 ft. long, and 3 ft. deep, nearly 72 ft. long. The construction and dimensions of them are like those in the large roof; the intermediate ribs are also the same as those in the large roof. So is the arrangement of gutters fixed on top of it, and also the covering. The arrangement of bracing and wind ties is also similar to that of the large roof. The ventilator is also the same. The main rib weighs $4\frac{1}{2}$ tons. One purlin, 6 ft. deep, weighs 12 cwt. One purlin, 3 ft. deep, weighs 1 ton 4 cwt.

The ironwork of roof only, in one bay of 96 ft., that is from centre of one pair of main ribs to the centre of another pair of them, weighs 35 tons.

The main rib is supported by a structure similar to that of the large roof, that is, by a frame formed by two shorter pieces of columns which are connected by a web. To the outer one is fixed the main gutter, of the same dimensions as on large roof. The intermediate ribs are also supported like those of large roof, all the details of connexions being the same.

The 72 ft. trussed purlins used in these roofs are the same that were used for carrying the roof over the nave of the Great Exhibition of 1851, also a large portion of the columns and girders made use of in the Sydenham Crystal Palace originally formed part of the same building.

Amsterdam Crystal Palace Roof.—(Plates 6 and 7.)

The area covered by this roof is 130 ft. $8\frac{5}{8}$ in. long and 64 ft. $1\frac{1}{4}$ in. wide, on each side of an oval dome—the entire length of the nave being 329 ft. 1 in. The roof is supported on

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each side of this dome by seven pairs of ribs, 2 ft. $1\frac{3}{16}$ in. apart, leaving a clear space between them of 19 ft. $8\frac{1}{4}$ in. The ribs of the principals are true arches. The intrados and extrados are concentric curves, being struck from the same centre with a radius of 31 ft. 6 in. and 33 ft. $1\frac{1}{2}$ in. They were so constructed, that, in being fixed, they were made to spring $2\frac{5}{8}$ in. outwards, making the distance from centre of building to face of column 31 ft. $7\frac{5}{16}$ in. They each consist of a top and bottom flange of one T iron, $4\frac{3}{4}$ in. × $1\frac{3}{4}$ in. × $\frac{5}{16}$ in. × $\frac{3}{8}$ in., and a plate $4\frac{3}{4}$ in. wide, $\frac{5}{16}$ in. thick, riveted to it by $\frac{7}{16}$ rivets of about 4 in. pitch. These two flanges are connected by two web plates, No. 9 B.W.G., 1 ft. 6 in. wide, one on each side of the T irons, riveted to them also with $\frac{7}{16}$ in. rivets. The entire available sectional area of this rib is 10·56 sq. in. The web plates are joined alternately in lengths of about 23 ft. 4 in. by a $\frac{3}{8}$ joint plate placed between the two web plates. It is 4 in. wide, and, for the sake of architectural appearance, riveted to them with $\frac{7}{16}$ in. flush rivets.

The rib is divided on its outer side, between a point 10 ft. 2 in. above the springing line and its centre, into seven equal parts. The purlins are carried by it in these intervals. They consist of simple ⊢⊣ irons 6 in. × 3 in. × $\frac{3}{8}$ in., with an available sectional area of 1·08 sq. in. in the top and bottom flanges. They are joined in lengths of 21 ft. $9\frac{7}{16}$ in. between each pair of main ribs by two joint plates $20\frac{1}{2}$ in. long, $5\frac{1}{8}$ in. wide, $\frac{3}{8}$ in. thick, and twelve $\frac{5}{8}$ in. rivets. These purlins carry the wrought-iron skylight bars, one length of the former divided into twenty spaces gives the distance of each skylight bar about 13 in. pitch. The skylight bars are fixed to the purlins by L iron brackets $1\frac{1}{2}$ in. × $1\frac{1}{4}$ in. × $\frac{1}{4}$ in., 3 in. long. The purlins are fixed to the main and intermediate ribs by two L iron brackets 3 in. × 3 in. × $\frac{3}{8}$ in., 4 in. long, by four $\frac{1}{2}$ in. bolts, with two $\frac{3}{8}$ in. washers and by two $\frac{5}{8}$ in. rivets. Between each pair of main ribs are two intermediate ones. They have the same extrados as main ribs, but are only 10 in. deep. They consist of a top and bottom flange of one T iron $3\frac{1}{2}$ in. × $1\frac{3}{4}$ in. × $\frac{5}{16}$ × $\frac{3}{8}$ in., connected by two web plates, like those in main ribs, No. 9, B.W.G., riveted to them with $\frac{7}{16}$ in. rivets of about 4 in. pitch. The web plates are connected in lengths of about 23 ft. 5 in. by one joint plate placed between them, $\frac{3}{8}$ in. thick, 4 in. wide, and six $\frac{7}{16}$ in. countersunk rivets. The entire available sectional area of this rib is 7·11 sq. in. Each of the ribs is supported by a column, so that the upper half of it is widened out to a sort of bracket, at a height of 11 ft. $7\frac{1}{4}$ in. above its springing line. This bracket is strengthened by $\frac{3}{8}$ in. plates placed between the two web plates, and two L irons 4 in. × 4 in. × $\frac{3}{4}$ in. riveted to each side of webs, and to a

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base plate $\frac{3}{4}$ in. thick, which is bolted to the top of column with five 1 in. bolts.

The intermediate ribs are supported at their ends by a timber beam. The inner T irons are bent round the flange of the upper one, and both are riveted to a $\frac{3}{8}$ in. base plate with eight $\frac{7}{16}$ in. rivets, which plate is screwed to the timber with three $\frac{5}{8}$ in. coach screws. Each of the main and intermediate ribs carry in their centre a triangular frame of cast iron, with ornamental filling in, bolted to them by $\frac{1}{2}$ in. bolts, 2 ft. pitch. It is in centre 1 ft. 7 in. high, and extends on each side about 5 ft. over the ribs, and supports in the middle the cast-iron ventilator. The ventilator is formed by two ridge purlins of a proper cross section, covered by a small ridge roof. It consists of a simple plate of a very flat angle, with proper water-tight joints, and a pocket for fixing ridge ornament along the roof.

The weights of this structure are as follows: Main rib, 1 ton $10\frac{1}{2}$ cwt.; intermediate rib, 13 cwt.; purlins for one bay, 1 ton 17 cwt.; skylight bars for one bay, 1 ton 18 cwt. 2 qrs. 11 lb. Total weight of wrought and cast iron in one bay of roof, 9 tons 15 cwt. The appearance of all the columns from inside the building is similar. The first tier columns support the gallery girders, and form an ornamental framework with brackets at the joint with the column. The columns rest on a stone foundation.

Although this structure forms a sort of stiff frame for resisting the horizontal thrust of the principals, still a strong wood structure is formed by the roof of the gallery acting along the whole nave as a horizontal girder of great resistance against side pressure.

Proposed Roof of the St. Pancras Station, Midland Railway.—(Plate 8.)

Although the particulars of this roof have been already published in *Engineering*, it was still thought advisable to repeat them here for the sake of comparison. The area covered by this roof is 690 ft. by 240 ft. The main ribs are 29 ft. 4 in. from centre to centre, and have three intermediate ribs between them at equal distances apart, carried at every 18 ft. 6 in. by trussed purlins between the main ribs. The form of the ribs is entirely novel. They spring directly from the ground, and are firmly connected to massive brick piers below the floor level. The curve of the ribs is of two radii of 160 ft. and 57 ft., meeting at an angle in the centre 100 ft. above the level of rails. The ribs are 6 ft. deep, and formed with open box flanges $10\frac{1}{2}$ in. deep; the flanges being braced together by diagonal channel irons and

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radial struts forming the ends of the purlins. The lower parts of the ribs, to a height of about 25 ft. from platform level, are constructed of plates and angle irons riveted together. The intermediate ribs are 10½ in. deep, and will be made most probably of angle irons braced with diagonal bars. The purlins are braced beams 18 ft. 6 in. apart. They are so constructed that they stiffen the main ribs laterally. The bracing is so arranged as to carry the proper proportion of each of the three intermediate ribs, besides assisting to keep the bottom flanges of the main ribs in place. The whole of the roof is braced horizontally to resist any strains that may be caused by the pressure of the wind either on the gable or on the side.

Ventilation will be amply provided for by open spaces in the skylights, along the whole length of the ridges, and also along the eaves where the glass overhangs the gutters. The lower sides of the roof are to be covered with glass ridge and furrow skylight, at right angles to the ridge, 152 ft. wide, extending nearly the entire length of the roof. There will be a gangway at the foot of each skylight along the whole length of roof, and each gutter of skylight will have a snow grating along its whole length, with cross stripes to enable the workmen to repair and paint any portion of the skylight. The horizontal thrust is partly taken by the heavy brick piers, which act as abutments, and partly by a wrought-iron tie running below the level of rails across the platform, forming one of the wrought-iron girders which support the latter.

Referring to the various roofs described, we find that in the Dublin Crystal Palace roof, with a clear span of 49 ft., one square of area covered with glass requires 9¼ cwt. of wrought and cast iron. The smaller roof of the Crystal Palace, with a clear span of 56 ft., a square of covered area with glass, requires 13 cwt. of wrought and cast iron. The Derby Market Hall roof, of 81 ft. 5 in. clear span, one square covered over partly with slates and partly with glass requires 15 cwt. of wrought and cast iron. In the large roof of the Crystal Palace, which has a span of 104 ft., a square covered with glass requires 12¼ cwt. of wrought and cast iron. In the Amsterdam Crystal Palace roof, which has a clear span of 63 ft. 2⅝ in., an area of one square covered with glass requires 15 cwt. of wrought and cast iron; and, lastly, in the Midland roof, of 240 ft. span, one square of area, covered partly with glass and partly with slate, requires 17 cwt. of wrought and cast iron.

In each of the buildings covered by these roofs we find a different principle employed in the construction of ribs and in the arrangements for taking the horizontal thrust.

In some cases, where the abutments cannot be made to resist

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the whole of the horizontal thrust produced by the ribs, the latter have to be constructed to a somewhat smaller span (in the Amsterdam Crystal Palace roof 2⅝ in., as mentioned above), in order to bring into the bottom flange of the same that portion of the horizontal thrust which the abutments are not able to take.

The stability of an arched roof is, like that of any similar structure, increased with its size, because in a roof or bridge of a large span the moving load is less in proportion to the fixed load than in such of a smaller span.

Drawing the curves of equilibrium for the equally distributed and the unequally distributed load, it is obvious that in large roofs the curves differ comparatively little.

The greatest stability and rigidity of the various roofs which have been discussed, must, therefore, be expected in the St. Pancras Station roof, on account of its superior heaviness.

In arched roofs no apparent provisions can be made for expansion by temperature, as the abutments are not allowed to give way; the influence of temperature will, therefore, only cause the crown to rise or to fall accordingly.

DISCUSSION.

The PRESIDENT said that the Society must be congratulated on having such a paper as this laid before them. It was very useful to have such a collection of important works described in such great detail, while it was a satisfaction to know that they had proceeded from the office of Mr. Ordish, a past President, and Mr. Lefeuvre, the Vice-President. Mr. Wessely's paper might not be quite so readable as some of the papers submitted, but he (the President) would venture to say that, when it was printed, it would be more referred to and more carefully studied than almost any paper they had had for the last two or three years. There was hardly time left to enter upon a discussion this evening. The next meeting ought to be devoted to that purpose.

Mr. ELLIS inquired how the Midland roof was to be ventilated. It had struck him that there would be considerable difficulty in overcoming the extra tension and compression on the upper and lower sides on account of the girder being continuous. He wished to know whether there would be an equal section throughout, or whether it would be worth while to save metal by not making the sections equal throughout.

Mr. ORDISH said he would state the arrangement at present proposed for the ventilation of the Midland roof, but that arrangement was subject to alteration. There was an intermediate rib, and the gutter would be on the main rib. There were wood

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bars, then an opening, and over that was a ventilator. This was very much like the arrangement of the Dublin roof. There was about an inch between the glass and the edge of the gutter, and that allowed ventilation. There was also a space of six inches the whole length of each ridge. By giving a large area, the ventilation was spread all over the roof.

Mr. SCHÖNHEYDER said that it was stated in the paper that the holes in the web plate of the main rafter of the Derby Market Hall were made by a screw press worked by a lever. That might be an arrangement adopted for the purpose of getting very great force, but he had seen very large holes punched in a much simpler manner by the common punching machine—namely, holes seven inches in diameter punched through a half-inch plate. That seemed to be a much quicker way of making the holes than that mentioned in the paper.

Mr. WESSELY said, as regarded the punching of the holes in the roof of the Derby Market Hall, he had only stated the way in which it was really done to show that, under certain circumstances, it was worth while to adopt whatever plan was most readily available. The punching might have been done in several other ways. He had lately heard that such holes had been punched by a steam hammer with great success. The steam hammer, by giving a sudden and rapid blow, cut the hole much sharper through the plate than a punch slowly passing down. The punch was always liable to bend the edges of the hole a little. The steam hammer was applied in a very simple way. A punch and die of the required shape were provided, the punch being in connexion with a strong spring; a stop was fixed to the apparatus to regulate the distance of the hole from the edge of the plate. When the plate was held in the right position, the steam hammer was caused to fall on the punch, giving it a rapid blow, which drove it through the plate, and on the raising of the hammer the spring carried the punch upwards and brought it out of the plate.

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March 19*th*, 1866.

ZERAH COLBURN, PRESIDENT, IN THE CHAIR.

ON ARCHED ROOFS.

BY CARL VON WESSELY.

ADJOURNED DISCUSSION.

Mr. CARGILL said he thought it was a pity the author had not gone a little more into the theory of the strains. It was a subject with which he was quite capable of dealing, and he might have shown how practical formulæ and deductions were arrived at. There were one or two formulæ in common use for calculating the horizontal strains and the resulting pressure on any portion of an arched rib. There had been an erroneous impression, amounting almost to a prejudice, in the minds of practical men, that the introduction of the higher mathematics was not conducive to the obtaining of practical formulæ for ordinary application. He could not make very much of the formulæ given in the paper as published in the *Engineer*, but he thought they might be given in a somewhat simpler manner. [Mr. Cargill then drew a diagram on the black board, explaining as follows:]

Suppose we take that to represent a semicircular arch, and it is required to ascertain the horizontal thrust at any particular point. We will take the crown as our origin, and draw our co-ordinates x and y to the point, x being the horizontal, and y the vertical. Now, if we represent the horizontal thrust by h, and the load between the centre and the point by w, we shall have the following equation:

$$h=\int_{o}^{x}\frac{w\,d\,x}{y}$$

This is the general equation for the horizontal strain at any point in the arch. In other words, the horizontal thrust is equal to the moment of the load divided by the rise of the curve of equilibrium. The two formulæ in common use among engineers for the horizontal strains on an arch are as follows: We generally assume the load to be distributed, as the case of a load at the centre is, in

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practice, of very little use; but, however, supposing the load to be at the centre, and that d represents the rise of the arch, which is generally taken to the soffit. Of course that is erroneous; but the amount of error is inconsiderable. It ought to be taken to where the line of equilibrium cuts the arch. Putting s for the span of the arch, and w for the load at crown, we have $H=\frac{ws}{4d}$. Now we can deduce this from the one given above very easily. In this expression, $\frac{w}{2}$ multiplied by the leverage is equal to the moment of the load. The leverage is, of course, half the span, and equal to $\frac{s}{2}$; and taking y, which represents the rise, and is equal to d, we obtain the above equation. Thus, from that which appears a somewhat abstruse formula, we can deduce a practical one.

The other formula, which is the more useful one, is where the load is supposed to be uniformly distributed, and using the same notation, we have $H=\frac{ws}{8d}$.

The author also mentioned that the horizontal strain is equal to that of a beam or girder of the same span and distributed load. This follows from the well-known principle of mechanics, that, with a load at the centre, and with the same load uniformly distributed over the beam, the latter strain is exactly one-half of the former. If the weight is distributed over the beam, we may get the central strain in this way. Let w be the weight per foot run, s the span, and x any distance from the nearest abutment. Then $H=w\int^{x} x\,dx$.

Integrating, we obtain $H=\frac{wx^2}{2}$.

Now take x between the limits of nothing and $\frac{s}{2}$. Were x equal to nothing, of course there would be no strain. When x is equal to $\frac{s}{2}$, as it is for the central strain, the equation becomes $H=\frac{w\,s^2}{8}$, but $w\,s=w$, and dividing by d, we have finally $H=\frac{ws}{8d}$, which is exactly half the strain found for a load at the centre.

It was remarked in the paper that, in order to obtain the strains upon the arch, we had to assume that the line of equilibrium passed through the centre of gravity of the different

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cross sections of the rib. That this is so was only correct on the assumption of an indefinitely thin or "linear" arch, and that it was altogether in a state of compression. In that case the line of pressure would pass through the neutral exis, and the thing would be done. One circumstance which prevented such a ready solution was, that when an iron arch, and, *à fortiori*, a brick or stone one, was loaded, the line of equilibrium dropped down, and assumed a different position; and thus, in addition to the compression, there was a bending strain which brought a transverse strain upon the arch. There was another strain which had to be determined, viz. the resultant pressure at any point, which was a strain compounded of two others. The resultant pressure always acted at a tangent to the line of equilibrium, no matter where that line might be, and could be obtained as follows: In the diagram let A B be a portion of the arch, and suppose the strain to be required at any point x. If we let P represent the strain, w the weight or load between the crown of the arch and point x, and θ the angle the line of pressure makes with the vertical, then we have $P = w\,x$ sect. θ, or if $H =$ horizontal thrust, $P = H$ co-sect. θ.

It was well known in practice that sections could not be dropped too rapidly. They could not be altered *per saltum*, but must blend one into another, and there must not be jumps in the different sections. At the crown of the arch, as could be easily seen, the tangent to the line of equilibrium was a horizontal line, consequently, the resulting pressure was equal to the horizontal thrust. It was a great pity there was not more information on this subject. With the rise and progress of railways, the horizontal girder really took the place of the arched girder; and while there were plenty of books treating on horizontal girders, there were none treating particularly on arched roofs, either of cast or wrought iron, from the very fact that they were not much used. The arch was replaced in iron by a different form. Passing to the practical part of the paper, he did not quite agree with the author that the arched form was more in accordance with the ideas of architectural beauty than any other form. In some of the finest examples of open roofs of the middle ages, the struts and ties were shown. It was not considered necessary to have a soffit or regular plane; and certainly the semicircular arch, as shown on the drawings, struck one as having a tunnel appearance. In the case of a roof, shown on one of the drawings as rising to a small point, the vaulted appearance was taken away simply by the inclination of the arch to a point. The other one would give more the idea of a tunnel than a roof, which always seemed to require walls as its natural support to spring from. The springing of a roof in a manner

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analogous to that of a bridge did not exactly coincide with his own idea of beauty. With respect to economy, a semicircular arch was certainly the most expensive kind of roof that could be adopted, because it required a greater amount of covering than any other. Another reason why the semicircular arch was not economical for a roof was that it necessitated very expensive side walls. There was a point which had struck him with regard to the Dublin Crystal Palace roof. There was, of course, a thrust exerted, and to resist that the author ran a cast-iron girder underneath. He did not see why such an expensive thing as a girder should be put when a mass of concrete, or granite, or limestone would have done equally well. The object was to keep the column from kicking in, and it brought rather a dangerous strain upon such a treacherous material as cast iron. The moment of the thrust was at one point, and the moment of the reaction was in another direction. It would catch the column right in the middle. That was, so to speak, tempting cast iron rather too much. There was another point in the details of the plans which had attracted his notice. It was that very small sections of iron were used to construct the larger sections. Of course, engineers wished to obtain the maximum of strength with the minimum of materials; but there was a consideration equally important—namely, to obtain a minimum of workmanship. He thought, as a rule, that it would be better to employ a little more material and a little less workmanship, because the workmanship of iron is one of the most expensive items in skilled labour. To obtain a section of 1½ sq. in. in one example there were four angle irons and a plate. It was a waste of labour to construct the above compound section with a top plate, a couple of angle irons, and a middle plate. A girder could not be made so strong that way as with the same section rolled out; and, secondly, it was a great deal more expensive. The section rolled solid could be supplied at about 9*l.* or 10*l.* a ton, but if constructed as shown in the drawing it would cost thirty or forty per cent. more. He agreed with the author that more information was required respecting the method of arriving at the strain of arched ribs. He did not know any English treatise which entered fully into the subject, but he had seen some papers relating to the subject in the *Annales des Ponts et Chaussées.*

Mr. Am Ende said he hoped the formulæ of Mr. Cargill would be saved for the Society, because the method seemed to be new in some of its details, but he thought they did not differ materially from those mentioned in the paper. For instance: $w\int x$ was in effect the same as $\sum_{x}^{xm} px$. It seemed to be

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understood that the curve of equilibrium would always pass through the neutral axis, or through the centre of every section. He believed that was not stated in the paper. This only gave the advice to lay the curve as near as possible to the neutral fibre, but it was also stated that the curve could only in a very particular case be within the neutral fibre entirely.

Mr. LEFEUVRE said he thought the paper should be regarded as treating generally upon the subject of arched roofs, and in discussing it we ought to look at the principal advantages which arched roofs had over trussed roofs. No doubt that for certain buildings there were many advantages in having arched instead of trussed roofs. For instance, in the cases of the Sydenham Crystal Palace, the International Exhibition, and the Great Northern Railway roofs, trussed roofs would have very much offended the eye. The architectural appearance of arched roofs were far preferable in roofs of a large span. The Charing-cross and Cannon-street Railway station roofs were dependent on the walls for support, and he must say that those walls were very hideous and very objectionable. The Midland roof, now in course of erection at King's-cross, the whole was carried to the ground, and the roof was not, in that case, dependent on the walls. The walls were only used as a blind to conceal the roof springing from the ground. The roof, being taken to the ground, was tied underneath the platform, for the purpose of counteracting the outward thrust which was common to arched roofs. The roof was virtually a circle, and the strains on every portion, including the tie-rods under ground, could be calculated. There was no doubt that the adoption of arched roofs was somewhat novel. Previously to the 1851 Exhibition there were very few arched roofs constructed. He believed that there was one at a riding-school at Moscow, having a span of 235 feet. Two or three of the largest arched roofs ever constructed were made of timber. The Great Western roof was not, strictly speaking, an arched roof, but an ellipse; he considered the arch was preferable in construction. Some of the roofs shown on the diagrams were so constructed that they had side aisles to counteract the outward thrust. The principal objection to arched roofs was the tendency to the outward thrust, which distorted them, and unless they had side aisles, or some means to counteract the outward thrust, they were liable to give way. In the case of the Dublin Crystal Palace roof, which was one of the most modern, the arch was made to bear directly on the roofs of the side aisles. There could not be a case more correct in theory than that one. In the original plan of the 1862 Exhibition roof no provision was made for the outward thrust, and as soon as the roof was loaded it assumed the form of an ellipse, and the whole building was in

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great danger of coming down. The system of trussing the side roofs was then applied, and in that instance the strain was taken down through the side aisles, and back to the columns, and down to the ground, and the whole roof was then tied underneath, and the building was then made secure. One of the great points which engineers should consider in large arched roofs was the force of the wind. This was not sufficiently attended to at present. Mr. Scott Russell calculated the wind force at 10 lb. a foot, and Professor Airey had calculated it at 40 lb. The wind exerted its force in all directions, and consequently the roof must be strong enough in all parts to resist the maximum wind pressure. The first speaker said he should prefer rolled girders in the case of the Amsterdam Crystal Palace roof. He (Mr. Lefeuvre) doubted whether the rolled girders, which were now being advocated, possessed any advantage over the built girders. There was a great loss of metal in the rolled girders. The only advantage was the saving of labour in building a girder together. The Amsterdam Crystal Palace girders were two feet deep, and they were constructed in the manner shown in the drawing, for the sake of architectural appearance. Instead of having a single web, there were two webs and a T iron, and a top and bottom flange, so that the angle iron was not seen outside the centre web. That might not be the best way of constructing a girder, but it looked much neater than the ordinary built girder. In roofs of large span it was a great advantage to have more weight than seems actually required. Weight tended to counteract the force of the wind and the outward thrust. He believed that in consequence of that it would be some time before steel was applied to roofs. Another objection to steel was that its quality was uncertain. With Bessemer steel, for instance, engineers could never arrive at two results alike. No doubt, in the course of a few years, we should have roofs of immense span. There was an especial advantage in having large arched roofs at terminal stations, because it was never known what the future traffic requirements would be as regarded platforms, and it was therefore desirable to avoid the use of columns, which would tend to interfere with alterations in the disposal of the area of the station.

Mr. Olrick said, a gentleman had stated that rolled girders would be cheaper than built-up girders; that depended, however, on the size required. When they were very large, it was cheaper to build them up in the ordinary way than to roll them; and *vice versâ*.

Mr. Phipps said, he saw upon the diagrams certain curves, which, no doubt, represented the curves of equilibrium suitable to given loads, some having to resist the wind as well as the

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statical loading; but there was one point which the diagrams did not appear to illustrate. Having to build an arch of any given magnitude, how are we to fix the position of that particular curve of equilibrium which is the one appropriate to the weights and forces applied? If that could be done, as he believed it could, it remained only to know the proportions in which it divided the depth of the arched rib at any point. If it crossed the axial line of the arched rib, there was at that point a fair strain upon the whole section; but whenever it travelled away from the true neutral axis, the strain no longer remained equal over the whole area of section, insomuch that, if the arch were of a plain rectangular section, and the centre of pressure were removed only one-sixth part from the neutral axis, the pressure would be doubled upon one of the outer edges of the arch, and the other would be relieved from pressure altogether. Therefore, until some method was shown for fixing upon the true position of the curve of equilibrium in any given arch, he believed the main elements of the strength could not be calculated.

Mr. HOUGHTON said he could not for his own part see the advantage of an arched roof of this immense size. An avenue down a space of the size of the Midland Station, dividing it into smaller spans, would considerably reduce the price. He could not understand why roofs should be made so high, except as a hobby of the engineer. He believed great economy would result from putting trussed girders across and erecting warehouses on same above the station. That would also be an advantage in resisting the pressure of the wind, which is an important consideration. The plan of tying the arch underneath was probably very ingenious, but it would not prevent an arch of this size from spreading at the feet. These large roofs were anything but beautiful, and were a disfigurement to the metropolis. The ventilation of the roofs shown in the diagrams seemed to be well provided for, but he had found that the plan of fixed louvres was objectionable, because, in wet weather, a great deal of rain was let in when the wind was high; in fact, some of the large stations are unbearable on this account.

Mr. CARGILL said that the greatest wind pressure ever observed on the Menai Bridge was 40 lb. The greatest ever observed in this country was determined by Dr. Nichols, and was given by Rankine at 65 lb.; 28 lb. or 30 lb. was what was generally allowed for. He wished to know what depth of snow Mr. Lefeuvre allowed for; and also what strain Mr. Lefeuvre thought correct for the wrought iron. The roof was not subject to a moving load, but to a stationary one, and there was no doubt that a greater static strain per square inch than moving strain might be put upon wrought iron. He could not quite understand what

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was meant in the paper by the statement of the wooden struts being used for some of the intermediate girders or horizontal purlins.

Mr. LEFEUVRE, in reply to Mr. Cargill, said that the snow pressure varied in different districts, and that should be borne in mind in giving the necessary strength to a roof. In England, from 5 lb. to 6 lb. might be reckoned for snow. The wind was allowed for at about 30 lb. per superficial foot. As regarded the strain upon the iron, about 7 tons was generally taken; in the case of bridges the Board of Trade allowed only 5 tons. Where the iron was of a good quality, and every portion could be tested, a high strain might be put on a roof.

Mr. RILEY said there was a good reason why the inspectors of the Board of Trade limited the tensile strain upon wrought-iron railway girders to 5 tons per square inch; and there was a very good reason why that might be very much exceeded in roofs. For a statical load any structure of wrought iron might be safely strained up to the limits of elasticity, or nearly so. The limit of elasticity of common wrought iron varied from 8½ to 11 tons per square inch. With a perfectly steady load a tensile strain of 9 tons to the square inch would be safe; but when there was a moving load, the strain must be reduced. The experiments of Mr. Fairbain, as given in a paper read at the Royal Society, showed that a moving load of 7 tons broke down the structure. It was shown by Professor Rankine, in his work on mechanics, that the strain of a load passing over a bridge, at what was called by the mathematicians an infinite speed, was double the strain of a stationary load. Sixty or seventy miles an hour was a sufficient speed to greatly increase the effect of a load upon the fibre of the iron. He was of opinion that, except for the very smallest sections, a built-up girder was cheaper than a rolled girder. For anything as much as 12 in. deep and 2 or 3 in. wide, a built girder would be cheapest. Care should be taken to make a girder as strong in every part as in the centre. The riveting of girders did not seem to have received sufficient attention. The pitch of the rivets might be varied along the course of the girder. In a length of 30 ft. the rivets might have a pitch of 2 in. near the pier, and 6 or 8 in. pitch towards the centre, except as far as the keeping of the plates together was concerned. It was not the practice of the Board of Trade to put the strain at 5 tons. They took into account the shape of the compressed member, and the stiffness. If that was sufficient, they allowed it to pass. The limit of elasticity was the same both for compression and tension.

Mr. LEFEUVRE, in reply to the question concerning the testing of welds, said that he avoided welds as much as possible, but,

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when they were employed, he always assumed them to be as good as any other portion of the iron. Some practical gentlemen fancied that a weld was better than any other portion of the bar, but he had generally found that if there were any defect it was in the weld. As to the snow, he allowed as distributed equally over the curve of the roof the weight of 1·2 lb. That was the old Admiralty test.

Mr. WESSELY said that so many able remarks had been made, there remained very little for him to say as regarded his paper; but he wished to call attention once more to the diagrams, which showed the lines of pressure or curves of equilibrium.

Fig. 3 showed how different curves of equilibrium might be assumed for a certain arch, although the amount of the horizontal strain was not defined. One of them was above the arch, another one below, a third one could be drawn so as to intersect the central layer of the arch in two points, and would be the curve of equilibrium most nearly following the contour of the arch.

These three curves really gave theoretical expression to as many practical cases—viz.:

Firstly. Where the curve is above the arch.

Here the horizontal resistance of the abutments was less than the horizontal thrust of the arch, which is due to its own height; the curve of equilibrium could no longer pass through its crown, but rose to a certain height above the same. The tendency of breaking the crown by transverse strain, as indicated by this curve, could be balanced by a tie on the underside of the arch. Such was the ordinary trussed arch or bowstring.

Secondly. Where the curve of equilibrium is below the arch. Here the horizontal resistance, or the pressure of the abutments inwards, was greater than the horizontal thrust of the arch, which is due to its own height. This case, although not frequent in practice, still might occur in an arrangement where an arched roof abuts on either side against one of a similar description, but smaller in span. These smaller roofs would be similar to the bowstring, differing from it only by having their ties on top and their struts on bottom. The actual horizontal resistance of the abutments was in this case the horizontal thrust from the central roof, which would, in the side roofs, produce curves of equilibrium situated below their struts.

Thirdly. That case, where the curve of equilibrium intersects in two points the central layer of the arch, was represented by the well-known combination of an elliptical arch and two straight rafters outside of it being inclined from the centre towards the abutments.

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To face Page 66.

Fig. 4.

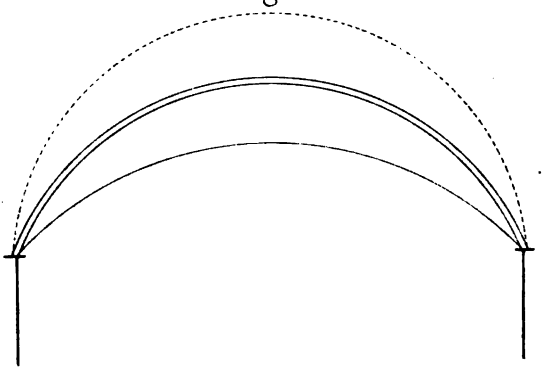


Fig. 5.

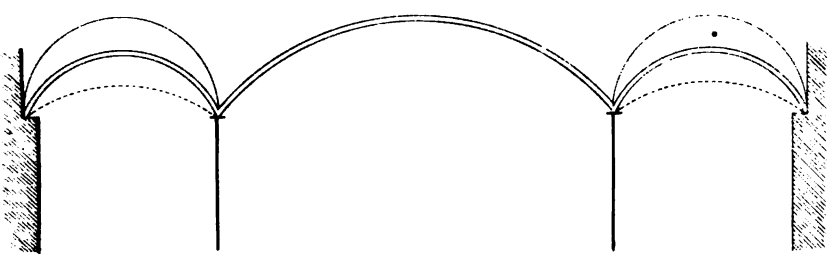
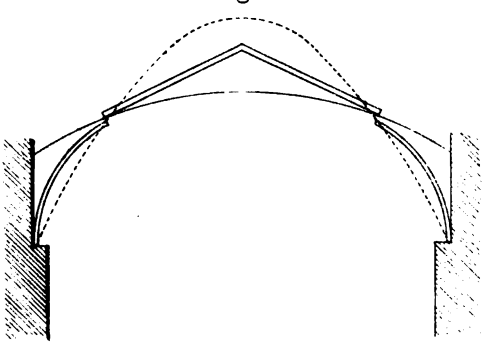


Fig. 6.



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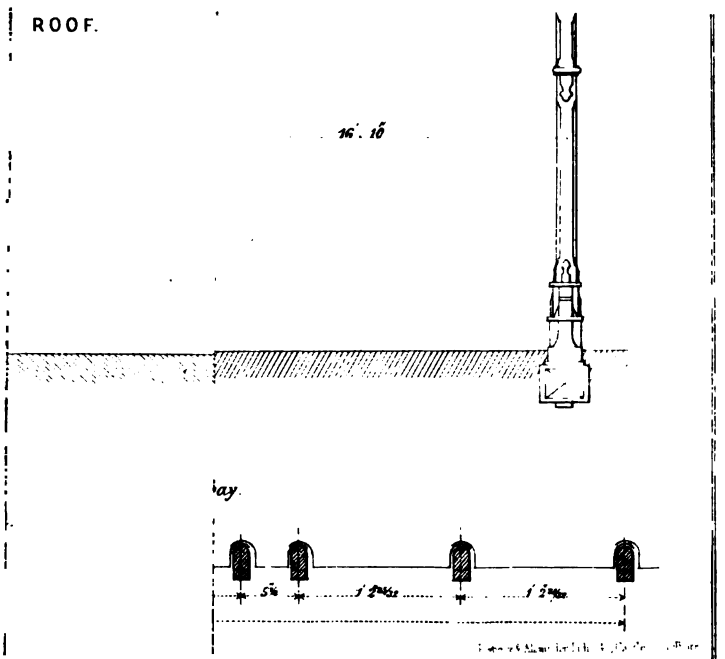
ROOF.



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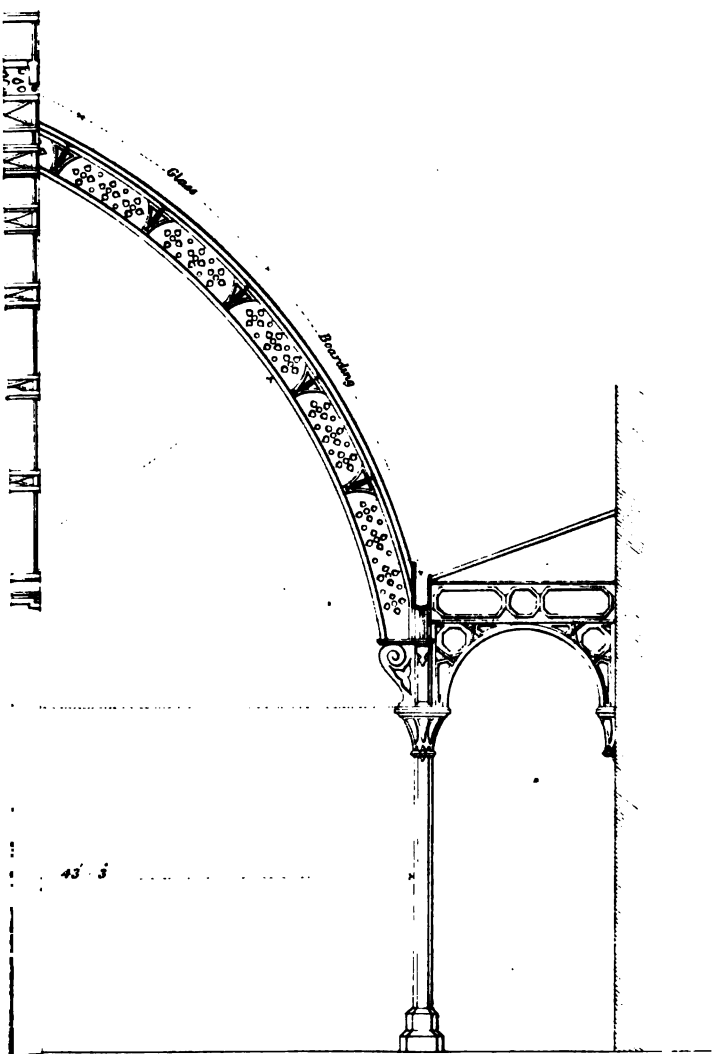

Newbery & Alexander Edin. 43, Castle St. Edinburgh

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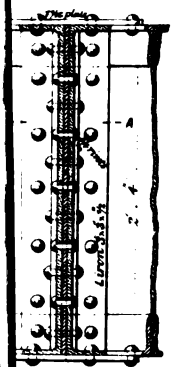
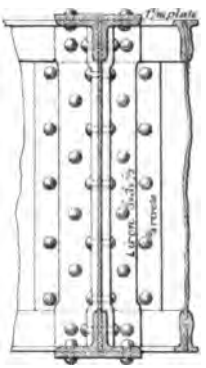
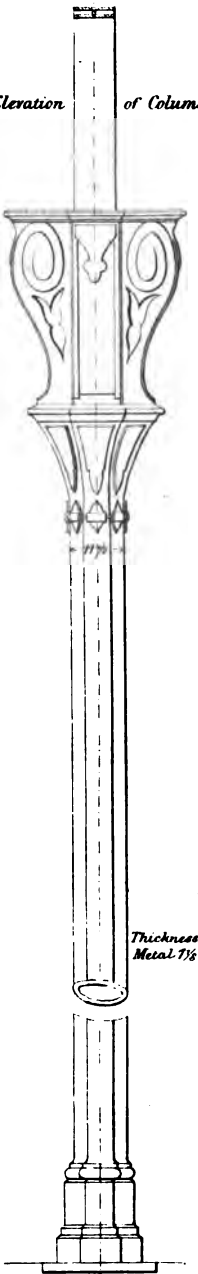
rv' Rib at Ridge.



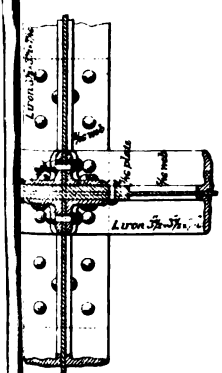
Section thro' Ridge Purlin.



Elevation of Column



al Plan thro' A.A.



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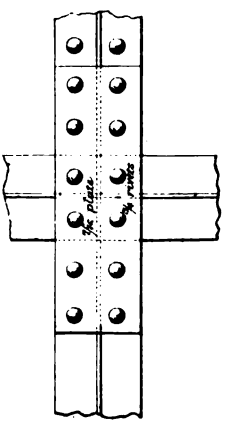

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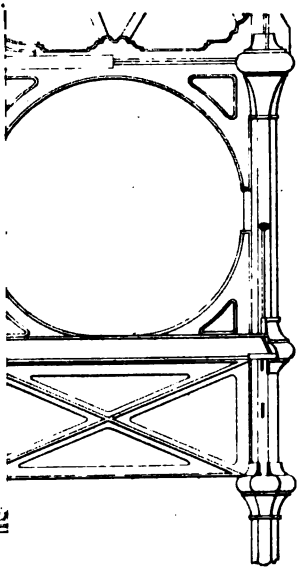

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Floor Li

nlarged Elevation of Rib.

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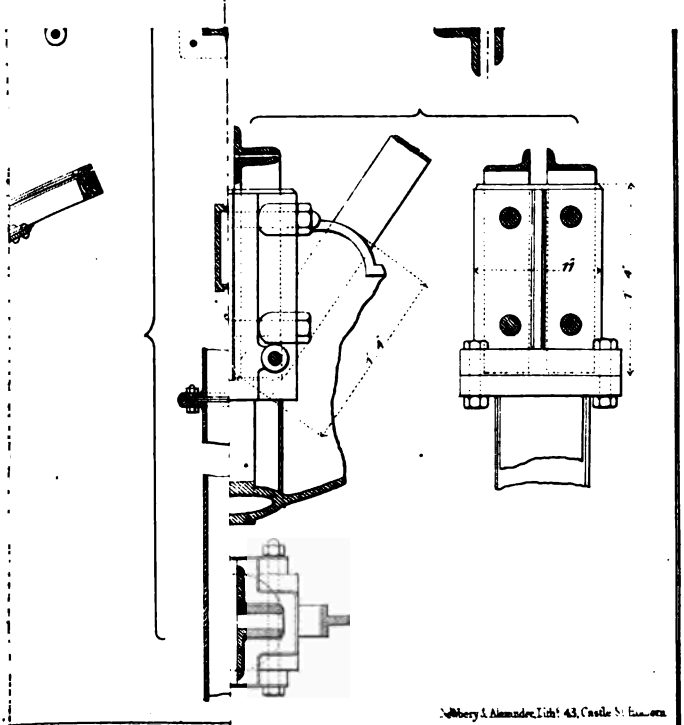

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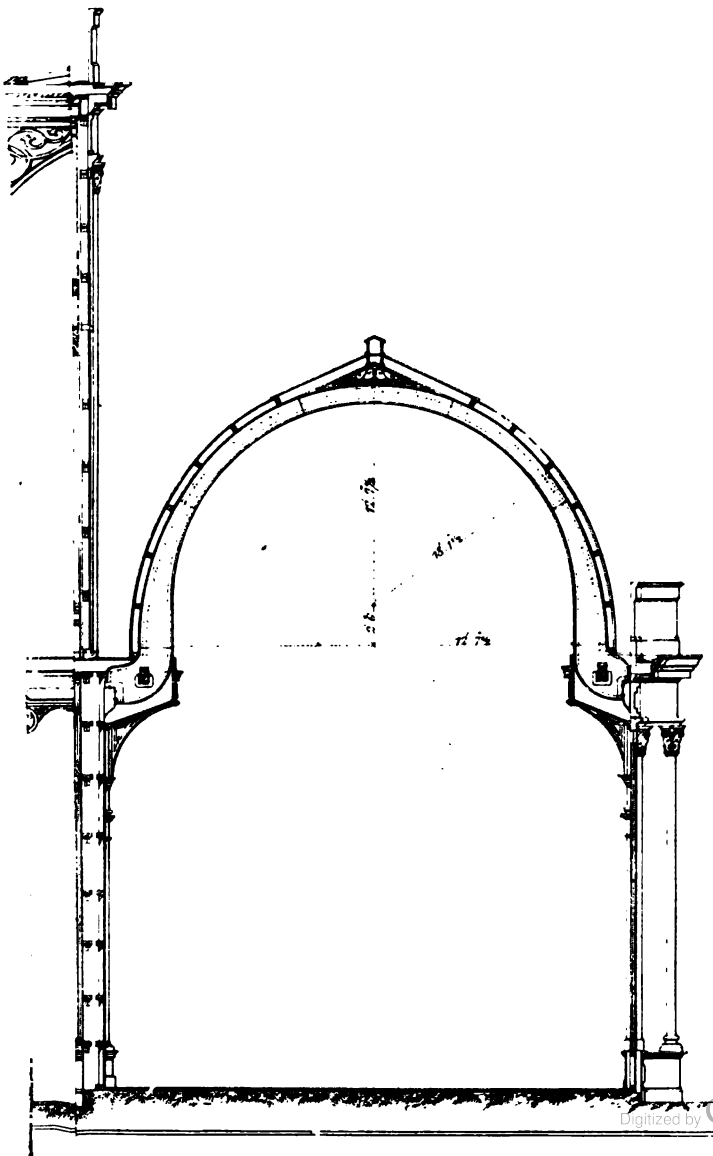
CRYSTAL PALACE.



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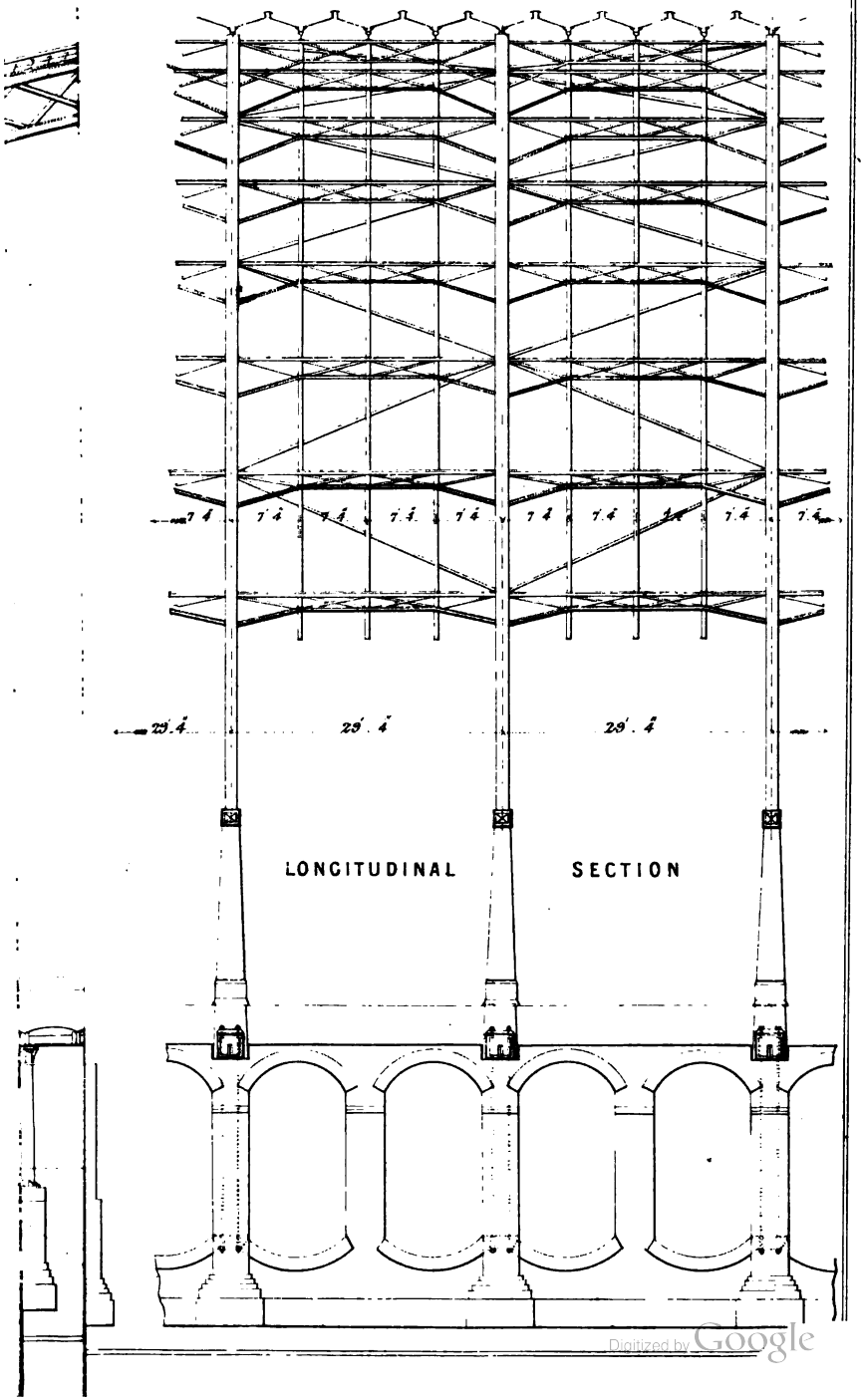

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A fourth case, where the curve of equilibrium is situated within the contours of the arch, did not require any further explanation.

The PRESIDENT said he believed the application of the arch to roofs was quite modern. He did not know what was the earliest use of the arch in such a way, but he believed the Moscow riding-school was now about thirty years old. The Great Northern Railway roof and the Paddington roof were among the earliest examples in this country. At Philadelphia there was formerly an arched bridge with 340 ft. span, and on the New York and Erie Railway there was one, not long since taken down, of 276 ft. span. The Midland roof was an enormous bowstring, with the tie concealed under the roadway. That seemed to be a very happy idea. It might be asked what need there was for such gigantic roofs, and whether it would not be more economical to keep to the old form. But an arched roof gave a noble interior; and the fact must not be lost sight of, that in the present age there was a growing taste for grandeur and magnificence. Whether we refused to recognise that strictly in connexion with engineering or not, we could not deny the fact. It would not do to quarrel with that taste, and it seemed to him that the Midland roof was a concession to it. At the same time there could be no doubt that the weight of large roofs increased in a greater proportion than their span; and therefore they had more stability. It had been shown that a semicircular roof had a horizontal thrust. That ought to be known to every engineer, but it was quite ignored in the Exhibition of 1862. Every one remembered how the temporary roof of the Western Annexe had to be strutted, through going over 16 in. at the tops of the columns. The strain of the wind was variable, and it was difficult to find the maximum. As regarded the snow, different allowances must be made in different countries. On American and Canadian lines it was always taken as equal to 30 lb. a foot. Beams could now be rolled to a very large section. About two or three years ago he had occasion to make inquiry as to their price. He found that large beams 3 ft. deep were rolled as two separate T irons, and welded together so as to form a web; and they could be supplied as bridge girders at 17*l.* a ton. Rolled beams of lighter section were very often supplied at less than 9*l.* a ton, which was scarcely more than the price of railway bars. Rolled beams were much more used abroad, especially in France and in the United States, than in England. The Society must feel that Mr. Wessely had given them one of the best papers that had been presented for many months. It contained a great deal of valuable matter, and would be an important addition to the Transactions.

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April 9th, 1866.

ZERAH COLBURN, PRESIDENT, IN THE CHAIR.

THE UTILISATION OF SEWAGE.

BY BALDWIN LATHAM.

INTRODUCTION.

IT has been very clearly demonstrated that the life and health of communities is in a degree dependent upon the observance of certain sanitary measures. That there is a necessity for such measures has been seen by the early religious ordinances of the Jews and other nations, and confirmed by historians who have touched upon the internal arrangements and conditions of ancient cities and towns, and supported at the present day by the nearly unanimous opinion of medical men, and by the statistical returns of this country. It is unnecessary therefore to enter into any argument or adduce any evidence as to the necessity of sanitary measures, as it may be taken for granted that the presence of atmospheric impurities, arising from the decomposition of animal or vegetable matter that may be allowed to accumulate in the midst of our populations, has a marked effect in extending the ravages or aggravating the character of a certain class of disease. It was the clear knowledge of the evils arising from harbouring decomposing matter in the vicinity of or under our dwellings that has called forth, within the last quarter of a century, certain legislative measures, the objects of which have been to give powers to local authorities to suppress the evils arising from cesspools and other abominations, and to sewer and cleanse the districts committed to their care. From remote periods, habits of cleanliness have been considered by some persons in every community as conducive to the preservation of health and life; yet communities as a whole paid little regard to sanitary measures, and it was not until cholera and other epidemic diseases had decimated our populations, and were still threatening us with their dire calamities, that the few sanitary reformers in our

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communities gained the ascendancy, and under their guidance a large number of towns have been sewered and drained which before were totally unprovided with any efficient system of drainage. At this period in the history of sanitary reform, the pioneers of the science were so impressed with the enormity of the evils arising from retaining decomposing matter in the vicinity of our dwellings, that they were led to look upon sewage as a nuisance to be got rid of as quickly as possible; so they poured it into the nearest stream or watercourse, in the hope that that stream would bear it harmlessly to the ocean, where it would be entombed for ever from sight; but the result has proved different from what was expected. Nature rebels against the waste, and the waters will not willingly and without an effort engorge so valuable a material; consequently we find it seething on the banks of our rivers, or returned by every tidal wave that rolls upon our shores, thus figuratively speaking to us in the strongest terms the true direction for its application. The benefits arising from the purification of the atmosphere, in every locality in which a thorough cleansing and sewering has been carried out, have had a marked effect in reducing the rate of disease and death; yet on the other hand it cannot be overlooked that the measures adopted have tended very materially to add to the pollution of the rivers and streams of the country; and as in a sanitary point of view the purity of our water supplies is of so great importance that we shall not, as a country, reap the full advantage to be derived from sanitary measures until our rivers have been freed from the abominations poured into them. The attainment of this object is the more necessary, when it is considered that many large and populous districts are entirely dependent for their water supply upon rivers into which a large amount of sewage is poured, and that this sewage, which in a river is a bane to the country, would under other circumstances if properly utilised, go to swell the wealth of the nation.

What is Sewage, and what is its Value?

Literally, sewage is the matter conveyed by sewers, and consists of waste water containing the liquid and solid excrements of men and animals, the soap refuse and washing from kitchens, &c., the drainage of slaughter-houses, manufactures, and streets. The constituents of sewage vary considerably with the habits of our population, and with the different systems of drainage and water supply in operation. So great is the variation in the quality of sewage, that its chemical value cannot be satisfactorily ascertained except after a long course of experiments; yet though

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a difference will be found in the value of sewage as based upon chemical analysis, in few towns can it be said that the sewage is of so little worth, and the advantages of utilising it so small, as to render it not worth the trouble and expense of attempting; for in settling the question of the utilisation of sewage, it must not be lost sight of that there are other and higher considerations than a direct money profit, which render it necessary, if not compulsory, to utilise the sewage produced by all populations; and, in carrying out these higher considerations, the persons to whom the duty is entrusted will find from experience that a proper and complete system of utilisation will generally give a fair remuneration in return for the trouble bestowed on the matter. But let it not be understood that sewage can always be profitably utilised: there are exceptions to every rule; and in carrying out the works necessary for the purification and utilisation of sewage, it is possible either to expend too much capital at the outset, or the works may be so arranged that heavy working expenses may swamp the whole of the pecuniary gains. In all works for the utilisation of sewage, simplicity is the great object to be attained; and it is surprising how nature will assist and aid the simple efforts to aid her in the fulfilment of her purposes, whilst, on the other hand, the most expensive systems, if not in accordance with the simple teachings of nature, must turn out to be failures.

The value of sewage has been variously estimated by different persons, and under different circumstances; and in giving the following estimates of the value of the constituents contained in sewage, it must be fully understood that the value realisable for sewage is totally distinct from the money value of its constituents.

Baron Liebig has estimated that one ton of London sewage is worth 1·84 penny per ton, guano being 7*l.* 14s. per ton. According to this estimate, the annual value of the sewage of London, when calculated, is equal to 15s. 4d. per head of the population. But as Baron Liebig states that 828 tons of sewer water are equal in value to one ton of Peruvian guano, and as he compares the value of the constituents of sewage with the value of the constituents of guano, at the present marketable price of guano, the sewage must have a value of nearly double that which the learned baron assigns to it.

Dr. A. W. Hofman calculates that the suspended matter in sewage is worth 15s. 3d. per ton, while the solid residuum from the dissolved matter is worth 5*l.* 5s., and that all the constituents of sewage when reduced to a solid form are worth 6*l.* 0s. 3d. per ton; that one hundred tons of sewage as discharged from

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the London sewers are worth 17s. 7d., or 2s. 2½d. for the suspended matter and 15s. 4½d. for the dissolved matter. At this rate, a ton of sewage is worth rather more than 2d. per ton, or the annual value is worth 17s. 7d. per head of the population, provided 100 tons correctly represents the amount of sewage due to one individual, and which there is every reason to believe is correct in the case of London; but the actual figures, calculated by him from the total value of the London sewage, give 10s. 8d. as the annual value per head of the population. As Dr. Hofman calculates the total value of London sewage is 1,385,540*l.* per annum, and as this sewage is produced by 2,600,000 persons, and is calculated in bulk at 266,000,000 tons, it must be quite evident that either the total value of the sewage is below the value, or, what is more probable, that 2d. per ton is too great a value for the sewage.

Messrs. Hofman and Witt have estimated the value of the annual voidings of an adult male as follows:

	Solid matter.	Ammonia.	Value.	
	lb.	lb.	s.	d.
Urine . . .	61	15·8	10	0½
Fæces . . .	34	2·3	1	8¾
	95	18·1	11	9¼

Dr. Thudichum estimates the value of the urine of an adult male as follows:

Solid matter.	Ammonia.	Value.	
lb.	lb.	s.	d.
47	15·9	10	3½

and that 2,800,000 persons of a mixed population are equal to 2,000,000 adults. A mean result of the estimates of Messrs. Hofman and Witt and Dr. Thudichum, as taken by the "commissioners appointed to inquire into the best mode of distributing the sewage of towns, and applying it to beneficial and profitable uses," gives the value of each individual of a mixed population as:

	Ammonia.	Value.	
	lb.	s.	d.
Urine . . .	11·32	7	3
Fæces . . .	1·64	1	2¾
Total	12·96	8	5¾

and an estimate made by Messrs. Lawes and Dr. Gilbert tends to show that the average value assigned in the estimates of Messrs. Hofman and Witt and Dr. Thudichum is in excess of the value of the sewage. They consider that the amount

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of ammonia probably contributed to the sewers by a mixed population, including the supply from all sources, does not exceed 12½ lb. per head of the population, and that the annual value is 8s. 4d. per head of the population; so that if this 8s. 4d. worth of manure is contained annually in 100 tons of drainage and rainfall water, it will give the sewage an average marketable value of 1d. per ton.

Professor Way estimates the value of the sewage of Rugby at from 1d. to 1½d. per ton; but he considers the constituents of London sewage are not worth 1½d. per ton.

Professor Voelcker estimates the intrinsic value of one ton of sewage at 2d., but that this theoretical value of 2d. per ton is practically greatly reduced, and in some instances would be altogether lost.

Mr. Lawes estimates the value of the sewage of Rugby at 1¼d. per ton.

Sir C. Fox estimates the value of sewage at 1¾d. per ton.

W. Hope, Esq., estimates the commercial value of the sewage of London at 1d. per ton; he also computes the annual value at 6s. per head of the population.

J. J. Mechi, Esq., gave it in evidence before the Select Committee on the Sewage of Towns that he estimated the annual value of sewage at 16s. per head of the population, upon the assumption that the value of the sewage was equal to one-tenth the value of the food consumed, which value he set down at from 7*l.* to 8*l.* per head of the population.

Mr. Ellis estimates that the value of a ton of sewage is 2d. as compared with the guano at 11*l.* per ton, on the principle that 1250 tons of sewage contains as much fertilising matter as a ton of guano.

Mr. Morton, in his interesting and valuable paper on sewage read before the Society of Arts, calculated that in applying sewage in the meadows of Edinburgh, not more than ¾d. per ton is realised. If London sewage was utilised at the same rate, it would give an annual return of 6s. 3d. per head of the population.

The commissioners appointed to inquire into the distribution and utilisation of sewage have calculated that at Croydon, after deducting 4*l.* per acre as the estimated value of the land, that in the cultivation of rye grass ¾d. to 1d. is realised, and in the cultivation of meadow grasses ½d. to ¾d. per ton is realised. The value of sewage has generally been estimated by the amount of fertilising matter present in it; and this value has been asserted by various persons to lie between 1d. and upwards of 2d. per ton. Yet it is quite possible all parties may be correct when the vari-

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ableness of the article to be dealt with is considered; so that, owing to this very changeability of character, in estimating the value of sewage, it will be well always to compare it with some fixed standard. For this reason, the author considers that, in estimating the value of the constituents of sewage, it is far better to estimate it by the number of persons contributing to the sewers than by the price per ton of sewage; because once ascertain what is the value of the sewage of one individual of a mixed population, and you have a standard, which if not correct, is more correct than the value per ton when it is intended to be used in the case of towns in which there exists no reliable analysis of the sewage; moreover the value of sewage of any place, when based upon its analysis, can only be correctly arrived at after a long and expensive course of experiments; and although the value of a correct analysis of the sewage cannot be over-estimated, and in the case of some manufacturing towns where it is necessary that something more than the amount of fertilising matter present in the sewage should be ascertained, it becomes absolutely indispensable; yet as a general rule, once ascertain the value of the constituents of sewage as contributed by one individual of a mixed population to the sewers, and you have a standard of value which is easy of application in every case. It is true that the value of the fertilising matter is dependent upon the social position and habits of the population furnishing the sewage, and is greater in the case of an opulent district than of a poor district, so that in fixing the average value, it will be better to err on the safe side than that our calculations should lead to financial failure when other results were expected. The annual voiding of one individual of a mixed population, as based upon the mean estimates of Messrs. Hofman and Witt and Dr. Thudichum, gives, in round numbers, 8s. 6d. as the value of the fertilising matter produced; yet it must be quite clear that the whole of the fertilising matter does not find its way to the sewers, as in the most perfect arrangement some loss will occur. On the other hand, in addition to the voidings of the people, there is a vast amount of fertilising matter from other sources that finds its way into the sewers. From the observations that have been made on the sewage of London, it is probable that the amount of fertilising matter which finds its way into the sewers from all sources is about equal in value to that of the annual voidings of the population, or, say, 8s. 6d. per head. This theoretical or chemical value of 8s. 6d. per head of a mixed population is 2d. in excess of the value assigned to it by the commissioners appointed to inquire into the distribution and utilisation of sewage. For all practical purposes the estimate of the Sewage Commissioners may be

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taken. Having decided that the standard value is 8s. 4d. per head, it will be a simple matter for calculation in every town what returns are likely to be realised from the disposal for agricultural purposes of its sewage. Under some circumstances and in favourable seasons it is probable that the full value in agricultural produce may be realised from its useful disposal, because sewage has a value for some purposes distinct from its chemical composition, which value will be considered hereafter; but, as a rule, it may be taken for granted that its theoretical value cannot always be realised, as in every case the cost of transport and distribution must be deducted from its theoretical value before the actual returns can be ascertained.

Value of the Water of Sewage.

Water is the vehicle that transports the fertilising matter contained in sewage through our drains and sewers eventually to be dealt with by the agriculturist. To a mind trained under the present practices of the agriculturist, the presence of so much water as is contained in sewage is looked upon as baneful rather than of value, and its effects, if poured upon land throughout the entire year, are considered to be ruinous; yet when tested in the unerring school of experience how different are the results; and when the facts are fully considered, it is obvious that the very presence of water has a value. When fertilising matter is conveyed in water to the crops, the operation is so simple that the labour that otherwise would be required in spreading a solid manure is dispensed with, while the fertilising matter is equally and uniformly distributed with almost mathematical certainty.

When the fertilising matter is received in water to a great extent, any loss by evaporation is checked, and the loss that often occurs in the application of solid manures from adverse weather is diminished, if not banished; while the matter held in solution by the water is at once presented to the plant in a state ready for assimilation. The plant having its food ready prepared for it, grows rapidly, and as the period of growth is greatly shortened, a greater number of suitable crops can be taken from the same ground in a season under the irrigation system than under the ordinary processes of farm manuring. The obvious difference between the system of manuring with solid manures and liquid manures is this, that the solid manures are applied to the land, while the liquid are applied more directly to the plant. The land is the medium for applying the nutriment that goes to build up the tissues of the plant; but if a given amount

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of fertilising matter in a dry, and also in a liquid state is applied, the liquid manure is at once food for the plant, while delays must take place before the solid manure can be assimilated by the plant. Solid manure must lie exposed to atmospheric influences until it has become soluble, and then it must be taken into solution by water before it is food for the plant; so that it is quite obvious, all other matters being equal, that a greater number of crops can be taken from the same area of land under the liquid manure system than under the dry manure system, which is in fact equivalent to an increased area of land, with this advantage, that there is but one rent or first charge upon the land.

Water alone has been found to have a remarkably stimulating effect on the growth of plants. It may be said of a plant that it lives and grows by drinking, and not by eating; "for a plant is not like an animal, endowed with special organs to dissolve the food and make it ready for absorption; this preparation of the nutriment is assigned by another law to the fruitful earth itself, which in this respect discharges the functions performed by the stomach and intestines of animals." It is of no use to a plant for the soil to contain all the constituents it requires to promote its growth, if they are not in such a state as can be made available; the first requisite is that they must be soluble, and the second requisite is the presence of water; for water is the vehicle that conveys nutrition alike to the plant and animal. The quantity of water that enters the roots of a plant is so great that the fertilising matter held in solution is in a state of extreme dilution; and in fact a concentrated solution of fertilising matter acts upon a plant in an analogous manner to an atmosphere of pure oxygen upon a living animal—in short, it stimulates it to death. Water then modifies the stimulating property of fertilising matter, and tends to produce a steady and healthy growth, just as the nitrogen of the atmosphere modifies the stimulating properties of the life-giving oxygen.

The amount of water evaporated or exhaled by a plant may be arrived at from an experiment made by Bishop Watson, who found that on a light and hot sunny day, when there had been no rain for a month, plants of grass evaporated water in twelve hours equal to ·035 in. in depth on the surface that produced them; a similar experiment after a thunder-storm gave 0·87 in. Calculating from this latter quantity when the ground is moist, a plant of common grass will evaporate water at the rate of quite ten tons per acre per day, and assuming that this rate was only carried out for one-half the year, it would equal 1800 tons per acre per annum; such is the enormous quantity of water requisite to keep up the

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healthy growth of the plant, which at once testifies to the advantage of furnishing it by artificial means when required. Water has a beneficial effect in rendering soluble the inorganic constituents of the soil, and so converting them into food for the plants. It is well known that a plant has a discriminating power of selecting from the soil only such food as is suitable for its growth; therefore any matter that remains in the vicinity of the roots, and which is not required by the plant, acts injuriously if not removed, by taking the place of matter suitable for the growth of the plant. Now water, in circulating, as in irrigated meadows, has the power to wash away these particles of matter, which, when in excess, the earth loses its attraction for, consequently they are removed without injury to the land. The circulation of water on the face of an irrigated field has the property of protecting a plant from the frost, provided the water is kept on constantly during the entire period of its duration; the reason for which is, that it requires a much more severe frost to freeze water in motion than when stagnant, and it is equally obvious that water preserves a higher temperature than hard frozen ground, so that a plant is much better protected when enveloped in water than when exposed to the open air. Water itself is also food for plants, as a certain amount of water is decomposed in passing through the tissues of the plant, which goes to build up its fabric. The objects of the agriculturist are fulfilled in the application of liquid manure with more certainty than under the dry system of manuring, as the greatest quantity of animal and vegetable food can be produced from a given area with far greater certainty and economy.

Value of the Temperature of Sewage.

Sewage has a special value distinct from the fertilising matter it contains, and also from the water that transports it; and this is its temperature. The value of its temperature cannot be overestimated in a country similar to this, in which extreme changes of atmospheric temperature often suddenly take place, and injuriously affect both plants and animals.

The value of the high temperature of sewage is more particularly demonstrated in the depth of winter and during long and continuous frosts. It is a rather remarkable circumstance, that when the greatest degree of temperature is required, the sewage possesses it, that is, the temperature of sewage has been found by the author to increase with the period of duration of frost. This is probably owing to the stagnation of surface water, and

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also to the habits of the people; as much less cold water is used in the depth of winter than at other times. So great is the value of temperature, that a crop under sewage irrigation may be seen growing even at the time of a severe frost. The author, from an experiment made during the winter of 1864 upon the irrigated fields of South Norwood, and carried out during a period of severe frost, was enabled to cultivate a crop of rye grass, which was only sown in the early part of the month of November; and when measured at Christmas the same year, the plant was found to be six inches in height, and was then growing luxuriously; and during the following year that crop was cut six times, the last of which was within one week of Christmas-day, 1865. During the experiment of the winter of 1864, in every case in which the sewage was applied, it had a temperature, in the coldest season, some degrees above that of the atmosphere, but not such a high temperature as the water used in another situation—the sewage-irrigated farm of Beddington, also under the author's direction. The temperature of sewage will be found to vary with the circumstances affecting the supply of water. Thus in a town supplied with water from an artesian well, the sewage will have a higher temperature in winter, and a more uniform temperature at all periods, than in a town supplied from a river or collecting area. Again, a town having but a small quantity of sewage to deal with, that sewage cannot be preserved at so high a temperature as a town in which the mass of sewage is great, as during a cold season the circumstances of exposure affect a small quantity much more readily than a large mass. The following Table gives the temperature of the sewage of Croydon as flowing to Beddington and South Norwood:

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Date.	CROYDON.								SOUTH NORWOOD.			
	Temperature of atmosphere at time and place of experiment.	Temperature of water supplied to town.	Temperature of sewage at filters.	Temperature of sewage passing on the land.	Temperature of sewage after leaving the land.	Temperature of atmosphere. Maximum.	Temperature of atmosphere. Minimum.	Rainfall in inches.	Temperature of atmosphere, &c.	Temperature of sewage in filters.	Temperature of sewage passing on the land.	Temperature of sewage after leaving the land.
1865.												
Feb. 13	34°	51°	55°	...	...	31°	24°		29°	38°	36°	36°
„ 14	...	...	...	...	...	33°	10°		*31°	41°	39°	33°
„ 15	...	...	...	...	...	35°	19°		28°	40°	40°	32°
„ 16	33°	51°	53½°	49°	34°	40°	28°		34°	40°	39°	34°
„ 17	Snow falling	51°	49°	...	...	40°	29°	·48	*34°	39°	38°	38°
„ 18	41°	...	49°	...	...	46°	35°	·10	41°	40°	29°	39°
„ 20	...	...	...	...	...	38°	20°		33°	40°	35°	35°
„ 21	32°	...	49°	49°	35°	36°	29°	·08	36°	39°	38°	33°
„ 22	39°	52°	51°	...	...	47°	35°		43°	40°	40°	41°
„ 23	50½°	53°	51°	...	...	52°	42°		48°	41°	41°	45°
„ 24	42°	53°	48½°	...	...	47°	30°	·60	43°	42°	...	...
„ 25	44½°	52½°	50½°	...	...	50°	35°		45°	41°	...	44°
„ 27	46°	52½°	50½°	...	...	53°	40°		46°	42°	...	46°
„ 28	51°	52½°	50°	...	...	51°	38°		48°	43°	...	48°
Mar. 1	47°	52½°	50°	...	...	50°	40°		47°	42°	...	45°
„ 2	48°	52½°	50°	...	...	48°	30°	·20	47°	43°	...	47°
„ 3	44½°	52½°	52½°	...	...	50°	20°		45°	42°	...	45°
„ 4	44½°	53°	51½°	...	...	48°	30°	·16	46°	42½°	...	43°
„ 6	41°	53°	50½°	...	...	41°	31°	·25	40°	42°	41°	40°
„ 7	41°	52°	50½°	...	...	44°	24°		40°	41°	40°	40°
„ 8	41°	52°	50½°	...	...	44°	30°		39°	41°	40°	40°
„ 9	39½°	52°	51°	...	...	45°	29°	·06	41° to 33°	41°	40°	40°
„ 10	45°	52½°	51°	...	...	43°	33°	·12	43° to 37°	41°	41°	43°
„ 11	43°	52°	51°	...	...	45°	33°	·03	41° to 35°	42°	41°	41°
„ 13	39°	52½°	51½°	...	...	47°	32°		41°	42°	42°	42°
„ 14	40°	52°	51°	...	...	43°	33°		39°	42°	42°	41°
„ 15	38°	52½°	51°	...	...	39°	32°		38°	42°	40°	38½°
„ 16	41½°	53°	51½°	...	...	45°	27°		43°	42°	42°	46°
„ 17	43°	52½°	51½°	...	...	46°	25°		...	...	...	...
„ 18	44°	52½°	51°	...	...	42°	33°		49°	42°	...	...
„ 20	33½°	52½°	51½°	...	...	35°	24°		42° to 32°	41½°	40°	39°
„ 21	39°	52½°	51½°	...	...	41°	28°		34° to 54°	41½°	41°	43°
„ 23	43°	53°	51°	...	...	44°	22°		...	...	...	...
„ 24	44°	53°	52°	...	...	45°	21°		...	...	...	...
„ 25	44°	54°	53°	...	...	45°	31°		...	...	...	...
„ 27	43°	53½°	52°	...	...	42°	23°		...	...	...	...
„ 28	39½°	55°	53°	...	...	49°	25°		...	...	...	...
„ 30	47°	55°	53°	...	...	48°	26°		...	...	...	...
„ 31	59°	54°	53°	...	...	58°	44°		...	...	...	...
April 1	56°	53°	52°	...	...	56°	29°		...	...	...	...
„ 3	56°	53½°	53°	...	...	59°	36°		...	...	...	...
„ 4	60°	53½°	53°	...	...	62°	38°		...	...	...	...
„ 5	58°	53½°	52½°	...	...	59°	47°	·09	...	...	...	...
„ 6	60°	53½°	53°	...	...	65°	44°		...	...	...	...
„ 7	62°	53½°	52½°	...	...	66°	40°		...	...	...	...
„ 8	67°	53½°	53½°	...	...	75°	37°		...	...	...	...
„ 10	67°	53½°	54°	...	...	76°	37°		...	...	...	...
„ 11	66°	53½°	53°	...	...	73°	38°		...	...	...	...
„ 12					...							
1866.												
Jan. 20	52°	52°	...	49°	49½°	51°	41°					

* Snow on ground.

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By referring to the foregoing Tables it will be seen that in time of frost the sewage has a high degree of temperature, which it loses when passed over the land. It has been found that when the atmospheric temperature is greater than the sewage, and more especially in sunny weather, the sewage increases in temperature on passing over the land; so that the effect of the application of sewage is to moderate the temperature of the land. The value of temperature is so great that in irrigation works it cannot be overlooked; and what is of greater importance to know is that, in the absence of heat, its effects, to a great extent, may be produced by giving an increase of velocity to the flow of the sewage, as it has been found from experience that motion is equivalent to temperature; consequently, in all irrigation works, where it is possible, the lower fields may advantageously have a greater rate of inclination than the fields that first receive the sewage.

Dilution of Sewage, and the various Measures that have been proposed for obviating it.

The extreme state of dilution in which the fertilising matter is often found in sewage has been used as an objection by many persons to its being applied to agricultural purposes; with others it has been an argument for the introduction of duplicate system of drainage; one set of sewers for the rainfall, the other for the sewage proper. Again, with many it has been the plea for abandoning the watercloset system, and adopting some other system not requiring the presence of water for effecting the removal of fæcal matter. In considering the subject of dilution in all its bearings, it must be remembered that sewage, be it ever so dilute, if allowed to enter a stream unpurified, will most assuredly foul and injure that stream; and when it is considered what large quantities of water are daily used for the removal of dirt and filth from our dwellings, apart from the watercloset system, it must be quite clear that such water contains an amount of filth that would foul any stream into which it is poured; and although this drainage water may not contain the same amount of fertilising matter as sewage proper, yet it contains quite sufficient to do mischief, as is daily evinced in those towns that have not adopted the watercloset system, and yet still have a system of drainage; and as the purity of water should be one of the first considerations of the sanitary reformer, upon sanitary grounds, if upon no other, water that has been once used to fulfil the domestic purposes of man should not again be turned into a stream from which it is probable his fellow-man may draw his only supply of water, without being first effectually purified. It

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has already been pointed out that the presence of water in sewage has a value, and it may be taken for granted that in all cases in which sewage can be applied by gravitation, the dilution, instead of being an injury, is a positive good; and consequently it is only in such cases as require the sewage to be raised artificially before it can be utilised, that dilution can seriously interfere with its value; and even when the state of dilution is such that the expense of raising it may not return a profit, yet when it is considered that no process of effectually deodorising sewage has been discovered, or is likely to be discovered, and that with all the systems of deodorisation, imperfect as they are, there is no gain, yet in the case of the most dilute sewage, although no profit may be made by its application, yet there is one great thing to be said of it that cannot he said of any system of deodorisation or chemical manipulation as at present practised, and that is, that it effectually purifies the sewage.

In an agricultural point of view, the dilution of sewage is no great drawback to its use; indeed, it is surprising how extremely dilute the vegetable kingdom at all times receives its food. The dilution does not diminish the absorbing power of the land for the fertilising matter; and to show how unimportant the question of dilution in an agricultural sense may appear, it will only be necessary to state that a field manured at the rate of 20 tons of rotten stable dung to the acre (according to Professor Voelcker's analysis) contains, ammonia, 530 lb.; phosphoric acid, 200 lb.; potash, 220 lb. With an average rainfall of 26 in. upon a field thus manured, we have a solution of fertilising matter far more dilute than sewage water.

	Stable Dung and Rainfall.	Sewage of London.
Ammonia . .	3·96 grains per gallon	7·20 grains
Phosphoric acid	2·40 "	1·44 "
Potash . . .	2·60 "	1·63 "
	8·96	10·27

Separation of Rainfall from Sewers.

The plan for separating the rainfall water from the drainage of houses and waterclosets has had many advocates, and appears at first to commend itself to our attention; but it will be found upon thorough investigation that it is a system unsuited for large cities or towns: 1st, because it involves a greater outlay in the cost of construction of the sewers; 2nd, the results to be attained will prove unsatisfactory; 3rd, the evils it is proposed to remedy are more imaginary than real.

A greater outlay in the construction of works would be in-

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curred, as a duplicate system of sewers would be required, and double drains from every house, which would nearly double the cost of the system of drainage as at present practised.

The system would prove unsatisfactory, as the rain that falls upon the surfaces of the streets, yards, roofs, &c., of towns acts as a scavenger, and carries with it many matters of great fertilising value, which if turned into any pure watercourse would most assuredly destroy its purity.

The evils the double system of sewers are proposed to remedy are more imaginary than real, as it has not been shown that a large amount of rain entering a sewer has any ill effect; it has not even been shown that it tends to dilute the sewage; but, on the other hand, in the case of London sewage, it was shown in evidence before Dr. Brady's committee, by Dr. Hofman, that the Savoy-street sewer yielded, on two occasions, 94 and 111 grains per gallon, but after a heavy storm the same sewer yielded as much as 296 grains per gallon, and other sewers gave corresponding quantities. It is not improbable that, in the examples furnished from London sewers, this excess of solid matter in times of heavy storms is due to the lodgement of solid matter in old and ill-constructed sewers, and that under a better system of sewers, so proportioned as to size and shape as to be always self-cleansing, no such solid matters could at any time find lodgement in them. This being the case, the rain would only convey into the sewers such matters as are washed from the surfaces which receive it; consequently the quantity and agricultural value of the matters conveyed by rain into the sewers must depend on conditions that vary considerably in every town. The following Tables are from the analyses of Professor Way, of rain water collected from the streets of London before reaching the sewer:

No. of Bottle.	Name of Street.	Description of Paving.	Quantity of Traffic.	Soluble.	Insoluble.	Total.
1	Duke-street, Manchester-square.....	Macadam	Middling	92·8	105·95	198·75
7	Foley-street (upper part)	„	Little	95·30	116·30	211·60
5	Gower-street.....	Granite	Middling	126·00	168·3	294·30
12	Norton-street	„	Little	123·87	3·00	126·87
3	Hampstead-road (above the canal)	Ballasted	Great	96·00	84·00	180·0
4	Ferdinand-street	„	Middling	44·00	48·3	92·30
2	Ferdinand-place	„	Little	50·80	34·30	85·10
10	Oxford-street	Granite	Great	276·23	537·10	813·33
6	„	Macadam	„	194·62	390·30	584·92
11	„	„	„	34·00	5·00	39·00

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Four samples of the waters described in the foregoing Table were submitted to separate analyses, with the following result:

Analysis of the Soluble Matter in different Specimens of Street Drainage Water.

	Grains in an imperial gallon.			
	Great Traffic.		Little Traffic.	
	Granite. No. 10.	Macadam. No. 6.	Granite. No. 12.	Macadam. No. 7.
Water of combination and some soluble organic matter	77·56	29·07	22·72	13·73
Silica	0·51	2·81	...	...
Carbonic acid	15·84	12·23	None	None
Sulphuric „	36·49	38·23	46·48	34·08
Lime	6·65	13·38	25·90	16·10
Magnesia	None	23·51	Trace	3·50
Oxide of iron and alumina, with a little phosphate of lime	2·58	1·25	...	...
Chloride of potassium	None	10·99	None	2·79
„ sodium	53·84	44·88	18·44	19·70
Potash	82·76	18·27	8·75	5·23
Soda	...	...	1·58	...
	276·23	194·62	123·87	95·13

Professor Way adds: "So far as London is concerned, and considering only the composition of the liquid which reaches the sewers in time of rain from the streets, it seems pretty certain that it would be as valuable in a manuring point of view as the ordinary contents of the sewers. There would seem no reason, therefore, to exclude such waters on the ground of the dilution and deterioration of the sewage to which they might be supposed to lead." However much the evils arising from the introduction of rain water into sewers are magnified, it is clear it does not injure the sewage for agricultural purposes. Moreover, it should be borne in mind that the periods of excess of rainfall in this country are limited, and that, as a rule, over half the rain falls within a period of from twenty to thirty days; of the other half, if taken as being uniformly distributed throughout the year, and after making reductions for evaporation and absorption, the proportion of the latter half of the rainfall that finds its way to the sewers is really infinitesimal. In the cases of London, Mr. Bazalgette has recorded the fact that $\frac{1}{4}$ in. rain did not furnish more than $\frac{1}{8}$ in. to the sewers; and $\frac{4}{10}$ in. of rainfall more than $\frac{1}{4}$ in. to the sewers. There cannot be any doubt that the

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commercial value of sewage water when containing rain water is less than if the fertilising matter was contained in less liquid; and when the sewage has to be lifted to considerable height the commercial result will be in favour of a concentrated solution of fertilising matter. But in the application of sewage it must never be lost sight of, that the question is not one entirely of utilisation, but of purification; and on the latter account it would not be advisable to divert all the rainfall from the sewers: yet it should not be lost sight of that the rain water, before entering the sewers, might be collected and used for many purposes, and thus materially diminish the quantity of water required to be brought into a town, and consequently at the same time diminish the cost to the inhabitants of procuring water supplies.

Separation of Fæcal Matter from House Drainage and Rainfall.

This system, like the system of separating rainfall from the sewers, requires either a duplicate set of sewers and drains, or other special arrangements that would involve in construction a greater outlay than required when but one system of sewers is in use. The advantages of this system are to be ascribed solely to the increased commercial value of the portion of the sewage separated from drainage water.

In every system for the collection of fæcal matter, the life and health of our populations must be considered as of far more importance than the agricultural value of the sewage; consequently those who have to decide upon the best system to be adopted must be careful to look at the subject, first from a sanitary point of view, and secondly from the agricultural point of view. This system of separating fæcal matter from the ordinary drainage will require either a certain amount of water to be admitted into the drains for conveying the fæcal matter, in order to transport it to its destination, or it will require cesspools in close proximity to our dwellings, from which the matter must be removed by manual labour, as practised in some parts of Paris, and by the Ureka Manure Company in this country. In considering the result of this system, it must be borne in mind that great evils result from cesspools of every description in proximity to our houses, and it would certainly be a retrograde step if, in order to realise the greatest results aimed at under this system, cesspools, in any form or shape, should be again introduced. If however the duplicate system of sewers is adopted, without the intervention of cesspools, a larger quantity of water must be used when distributed over the two systems, in order to keep each system

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in working order; for it must not be lost sight of that the quantity of water ordinarily used under the watercloset system would not act so effectually in keeping the drains and sewers clear from obstruction, if it were not assisted by the water used for other domestic purposes.

It has been already mentioned that rain water carries with it to the sewers many objectionable matters; but the amount contained in such rain water sinks into insignificance when compared with the matter contained in the waste water from our houses; and assuming that this system be carried out, and that the drainage water be turned into our streams unpurified, it would tend very materially to pollute them, and at the same time waste much valuable fertilising matter. In proportion as the separation of the drainage of waterclosets from house and refuse water takes place, so will such refuse water contain proportionally less fertilising matter; consequently, in utilising the sewage of a town under the system, we shall have two solutions to deal with, one containing the fæcal matter, and rich in manurial properties, the other, the refuse and rainfall water, containing much less fertilising matter, yet quite sufficient to create a nuisance if admitted into any pure watercourse. And as it is absolutely necessary for the purpose of purification, that the contents of both systems of sewers be utilised and purified, they cannot be utilised with as much advantage separately as when combined. The separation of fæcal matter from drainage and rainfall is carried out in most towns in which no works of drainage have been constructed, and yet in but few instances do the owners of the fæcal matter get anything for it, but, on the other hand, they have often to pay to have it removed. There are other towns which have a system of drainage, and which still separate the fæcal matter from the rainfall and drainage by a system of cesspools, ashpits, or soil-boxes; yet in not one of the places in which the system is in operation does it give any return to the town. Manchester may be taken as an example of this mode of dealing with the fæcal matter of a town, and yet we see that at Manchester the corporation annually lose upwards of 7000*l.* by the system in operation; in addition to which, it cannot be lost sight of that the mortality of Manchester is upwards of 30 in the 1000, the mortality of London being but 23, and of Croydon but 20. At Hyde, in Lancashire, which is under treatment by the Ureka Sanitary and Manure Company, the solid and liquid fæcal matters are collected in boxes, that are removed by manual labour as soon as filled, and taken to the manufactory of the company, where the ammonia is fixed by an acid; the greatest portion of the water is then evaporated, and the mass is afterwards brought into a dry state by being mixed with fine dry ashes,

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and is ready for sale. The company, it must be recollected, make a charge of 2s. per house to all persons who adopt their plan, in addition to which they get the fæcal matter unmixed with water. If this charge of 2s. per house is fairly analysed in a town, say, the size of Croydon, a sum equal to 600*l.* per annum would have to be paid for removing the fæcal matter only; and as it would still be necessary to sewer and drain, and also to purify this drainage water, no saving in the cost of construction would result; so that of this 600*l.* which would have to be paid by the inhabitants, if fairly compared with the results realised by irrigating with town sewage, it will show most conclusively that no possible advantage can arise to towns by selling or manufacturing its fæcal matter into manure, and still having to purify its drainage water. From the foregoing observations the following conclusions may safely be drawn of this system: 1st. The first outlay in the construction of works and the expenses of maintenance will be greater than when but one system of sewers is adopted. 2nd. If under this system cesspools are to be continued or introduced, in a sanitary point of view, the system will be pernicious to life and health. 3rd. If a duplicate plan of sewers are used under this system, it will not give so good a return as if a cesspool or other receptacle were used, and a greater quantity of water will be required for flushing and keeping clear the two systems of sewers than would be required with but one system of sewers. 4th. The system cannot be carried out without polluting the watercourses of the country, unless the contents of both systems of sewers are first purified. 5th. That the contents of both systems of sewers will contain fertilising matter which it is desirable to utilise; but no advantage will be gained by separately dealing with the contents of each system of sewers.

Separation of Liquid from Solid Excretion.

This plan, that has been proposed upon several occasions, is intended to separate the urine from the ordure, and convey it by a special system of pipes to some locality where it is to be reduced to a solid and portable manure. If a town had no other object to consider than making a profit in an easy way, probably a system like this would be likely to succeed; but when it is fairly considered that the sewage of a town must be dealt with in order to purify it, no advantage can possibly accrue by robbing the sewage of its most valuable constituents, and thus leaving a large quantity of comparatively poor sewage to be applied, under the most disadvantageous circumstances; and moreover all that has been urged against any system re-

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quiring a duplicate system of sewers will with equal force apply to this system.

Principles of Purifying Sewage by Utilisation.

Much misunderstanding has arisen as to the theory of the purification of sewage by its utilisation. It is common to find persons who suppose that the sewage is absorbed by the land mechanically, just as any solid manure would be mixed with the soil, or just in a manner analogous to that in which a sponge absorbs water; consequently, it has been considered by many persons that porous sandy soils are the only soils fit for the utilisation of sewage; than this there cannot be a greater mistake. Other persons, again, suppose that the roots of the plant under cultivation extract the fertilising matter directly from the sewage; and this again is a mistake. For it is found that the purification, and consequently the absorption, of fertilising matter is at all times and all seasons most perfect; consequently, this process of purification cannot be due to the mechanical absorption of the sewage by the soil, for if it were, when the pores of the soil are filled with sewage, or even with water in time of rainfall, we should expect the purification to fall off; yet experience shows that in time of rainfall, when there is more sewage, and the land is completely soaked, the purification is as complete and as perfect as at any other time. Again, to show that it is not the roots of the plant that extract the fertilising matter from the sewage, it is found that at night, when the plant may be said to be at rest—for in the absence of light a plant cannot fully utilise fertilising matter — and also in the winter months, when vegetation is by no means as active as at other times, it is found that the purification of the sewage still goes on perfectly and without intermission. The purification of sewage is due to a very beautiful property possessed by all soils to a greater or less extent, which is the affinity soils have for the fertilising matter, and their power of retaining it till required by the plant. Clay soils have a much greater affinity for fertilising matter than pure sandy soils, and it is possibly due to this property that clay soils excel in productiveness more than any other when treated with sewage. In utilising sewage, the soil performs the threefold action of extracting the fertilising matter, then fitting it for the food of the plant, and lastly, retaining it until required for the use of the plant. That this is the probable explanation of the process of assimilation may be taken from the fact that clay soils, which are really less mechanically absorbent than sandy soils, are as effectual, if not more so, in the purification of sewage. Again at night, when

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the growth of the plant is at rest, and yet the circulation of the sap is going forward, being kept up by the process of evaporation from the leaves of the plant and the capillary attraction of the roots, it is found that the gaseous matter prepared in the soil is partially evaporated from the plant; which would go to show that it has been fitted for the food of the plant, and it only needs the active property of light to properly utilise it. Again, probably the best proof that the soil attracts and retains the fertilising matter of the sewage we find in the fact that the first crop in the season on a sewage-irrigated farm will nearly always equal in weight one-half of all the remaining crops of the season, which shows that the fertilising matter stored in the winter has been made use of by the plants in the spring. It has been thought by some persons that, as some of the roots of the plants on an irrigated field spread themselves over the surface like a spider-web, that they directly take up the sewage; but then it is more generally known that this property of the spreading of roots is not peculiar to irrigated fields, but is also found in many other fields when the crops are heavy, and that it never takes place until the crop has grown to such a height as to completely shelter the roots, that in all probability the phenomenon has no direct connexion with the sewage, but is rather due to the rapid growth of the plant, and the absence of light at the roots, consequently, the roots under the circumstances are induced to spread themselves more or less in all directions.

Mode of Utilising Sewage.

Primarily, the modes in which sewage has been proposed to be distributed over land may be classified under the following heads:

1. Subterranean irrigation. 2. Underground pipes, and hose and jet distribution. 3. Surface channels. 4. By submersion.

Each of these systems has its modifications, but all systems may be reduced to either one or other of these classes.

Subterranean Irrigation.—Under this system the sewage is proposed to be passed into porous pipes, laid sufficiently deep in the ground to be out of the way of the plough. Indeed, under some circumstances, the pipes that are used for drainage may be made to subserve all the purposes of this system by merely stopping up their outlets during the time they may be required for irrigation, by which means the water will be dammed back, as it were, until it reaches the upper stratum of the earth and the roots of the plants. This system, which has been practised in some parts of Switzerland to a limited extent, is open to great objection, more especially when dealing with a solution of

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fertilising matter instead of with water, as has usually been employed with this system. The great evil to be guarded against in irrigation, with either water or sewage, is stagnation. Now, as drains laid in the ground for the purpose of drainage do not intercept the rain or other water falling on the surface of the land in its descent to the drains, but the water carried off by drains enters them at the bottom and flows up into the drain, because the drains form the overflows for subsoil waters, and, until the earth has been saturated to the level of the drains, no water will flow from them, but when this saturation is complete, then any additional water will overflow by the drains instead of rising to the surface; the condition then of all water below the level of the drains is that of a state of stagnation, which is prejudicial to any crop. This is well understood by the agriculturist; hence the system of deep drains to remove the subterraneous water as far from the surface as possible. Now, this system of underground irrigation would tend to raise the water to the level of the soil; consequently no circulation will take place, except that produced by the process of evaporation. The system of underground irrigation is wrong, inasmuch as it waterlogs the earth and induces a degree of coldness in it. There are other matters which require consideration when considering the system as connected with the utilisation of sewage. The great evil of this system is the waste of fertilising matter it tends to promote; for we cannot for one moment lose sight of the fact that sewage admitted into porous underground pipes, when the saturation of the ground is incomplete, will have a greater tendency to gravitate still deeper into the earth, and out of the reach of vegetation. Indeed, if it is desired to get rid of the sewage rather than utilise it, this is one of the best plans that could be adopted; in fact, it would be conversion of a field into an absorbing area similar in principle to the dry wells so prevalent in many parts of the country. But the getting rid of the sewage in this way is purchased at the expense of fouling the underground water. And as at the present time the purity of all water supplies must take rank even before the agricultural question of the utilising sewage, it is absolutely necessary that the system to be adopted shall preserve the purity of all water supplies.

Underground Pipes and Hose and Jet Distribution.—This system has not only been proposed time after time in this country for the distribution of sewage; it has been largely carried out, but with little success. There are various reasons for this want of success, and in considering them it will be well first to mention that this is a system likely to take the fancy of many persons—indeed it may be said to be a scientific toy which is outwardly more attractive than useful. In deciding which

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is the best system for distributing sewage, two things should be kept in view, the first is that all arrangements for its distribution should be as simple and inexpensive as possible; and the second is that, owing to the constant quantity of sewage to be dealt with, the arrangements must be capable of being worked at all times and seasons. Although in many cases it may be necessary to use a limited number of pipes for the purpose of conveying sewage to its destination, yet if it is possible to introduce a system that will be equally effective with another system, then the cheapest system must take the first place. In all cases in which water has to be forced through small pipes, a certain amount of force is expended in overcoming the friction in the pipes; to this must be added, in the hose and jet system of distribution, the necessity of having sufficient pressure in the water-mains for distributing the water over the field at a considerable altitude above its surface. Now probably 10 ft. of pressure is the least that would be required beyond that necessary for overcoming the resistance of the water passing through the pipes for the purpose of distributing it over the surface of the land by the hose and jet system. Now in the case of pumping, this extra head of water gives an increased power to be maintained; in fact, the expenditure of fuel may be said to be proportional to the height, and as in the case of the hose and jet system of distributing it will always be necessary to raise the sewage to a higher level than the land itself, this system cannot be so economical as one in which the sewage would only require to be raised to the height of the land. The fatal objection to the hose and jet system lies in its not being capable of application at all seasons. In a field in which sewage is proposed to be distributed by hose and jet, valves are arranged at suitable distances apart, to which the hose is attached, and this hose has consequently to be dragged over the surface of the land as the sewage is being distributed; consequently this system is quite inadmissible when the crop has grown to any considerable height, for if the hose has to be dragged over the growing crops, it would tend greatly to injure them; apart from this, in principle the distributing of liquid manure over the plant is wrong, as for the purposes of the plant the fertilising matter is required at the root, and not to be squirted over the plant. Indeed this indiscriminated istribution of sewage over a plant is attended with injury to the plant and a loss of fertilising matter. It injures the plant, because when the matter deposited on the plant evaporates it leaves a sedimentary deposit on the leaves, which tends to choke the breathing pores of the plant and also to give a gritty quality to the produce. To counterbalance these objections, it has been proposed not to apply the sewage during the latter

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period of the growth of the plant; but if this were done, the result would prove detrimental to the plant, because a plant habituated to an excess of moisture, if that moisture is suddenly and completely withdrawn the plant must suffer.

Distribution by open Carriers.—For the purpose of carrying out this system, the sewage may, if desirable, be brought to the head of every field in a covered channel, afterwards to be distributed by open channels or carriers. This system, which is the simplest and most effectual, may be carried out in various ways according to the configuration of the land. By this mode of distribution sewage can at all times be applied to the plant, for the sewage never comes in actual contact with the plant itself, it merely runs in a thin film over the surface of the ground at the root of the plant; the result is that the sewage may be applied during all stages of the growth of the plant up to the time of cutting the crops, and it only need be withdrawn from the land during a very limited period previous to the time of cutting the crop. In carrying out this system, it is absolutely necessary to prepare the land for the reception of the sewage by carefully levelling it, so that no holes or uneven places may exist. An uneven place will certainly retard the flow of the sewage; and if the sewage should be allowed to stagnate owing to any unevenness in the ground, it will effectually destroy instead of promote the growth of the crop. This system of irrigation is carried out in three ways, according to the contour of the land. The first plan, and probably the best, is called the pane and gutter system, and is admissible in all fields having a gentle rate of inclination. Under this system the land is laid out transversely between the open carriers that distribute the sewage quite level, the sewage is brought to the head of the field in an open or covered main carrier running transversely across it, or in the direction of its least fall, the carriers for distributing the sewage branch out from the main carriers and run down the field in the direction of its greatest fall; the sewage is distributed over the intervening space between the distributing carriers by means of stops being placed in the carriers, which dam back the sewage and make it flow right and left over the ground in an uniform stream; these stops are removed two or three times a day, according to circumstances. The second plan is called the catchwork system. It is suitable in all cases where the ground has a rapid rate of inclination, as for instance on the side of a hill. The plan consists of a series of carriers one above another; the sewage, flowing into the first and highest carrier, falls over the intervening land between it and the next lower carrier, which carrier receives the water and takes it up to redistribute it in the same way on the land below it, and so in turn the process goes on till the bottom

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of the field is reached. The carriers on this system run in contour lines round the hills, and are nearly level. The third plan is the bed system. This system is well adapted for level lands, or land having but slight fall; on this plan the land is laid out in a series of ridges and furrows, the sewage is brought on the top of the ridge and falls to the furrow. This arrangement, even in a country on a dead level, will give an artificial fall for the sewage, and guard against that stagnation which must be avoided in all works of this class. This system of open carriers, differing from the hose and jet system in the simplicity of distribution, would, in the case of pumping, only require the sewage to be raised to the level of the land; with this system the expenses of distributing it are small, as one man can with great ease more effectually irrigate in the same time ten times the same area he could under the hose and jet system. A modification of this system, but nothing like so good a plan, has been projected, and the sewage is proposed to be distributed by open wooden troughs; this modification of the system is subject to the same objections as every system requiring an apparatus to be moved about in the growing crop.

Irrigation by Submersion.—Although the previous system may be said to be submersion, yet not to the extent or in the mode adopted in this system. This system is extensively carried out in Piedmont and Lombardy in the cultivation of rice, and, unlike any other system, it is the only system of irrigation that is considered likely to affect the health of the inhabitants in the immediate neighbourhood of its operation. The special drawback to this system is due to the stagnation of the water, in fact, to the conversion of every field where it is practised into a swamp of the worst possible description; it differs from the ordinary irrigation system as much as a rippling stream can differ from a swamp; the one is considered innocuous, the other deadly. The mode in which the system is carried out is by raising a bank round the field to be irrigated, turning the water into it; the water is left in this position to be evaporated, and from time to time it is re-supplied with water. All the information that has been collected on the Continent, and likewise in India, where the cultivation of rice is carried on by this system of irrigation, goes to show that it is prejudicial to health, although with better means of drainage it is thought the condition of things may be greatly ameliorated. Yet in those same counties where irrigations on the other system have been and are most extensively carried out, no ill results can be traced to them; hence laws that restrict the cultivation of rice within certain limits of towns are extremely favourable to irrigation of the nature required for the utilisation of sewage. Although it is not likely that this system

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will be generally adopted for the purpose of utilising town sewage, yet in some cases it might be applied for manuring land, although very great care would have to be exercised in the selection of the places where it is to be carried out.

Selection of Crops to be Cultivated by Sewage.

As sewage is a manure that is produced at all times and seasons, and as it would be impossible to store it with advantage for use at particular seasons, it is obvious that some care must be taken in the selection of the crops best suited for its application, because although the constituents of sewage may be very favourable for the cultivation of some description of crops, yet those very crops may be unsuited, as is often found to be the case, for the reception of a large amount of water. Thus the cultivation of wheat would be unsuited for the constant and direct application of sewage, although the fertilising elements of sewage would be a very proper manure for its cultivation; but inasmuch as the presence of water induces the plant to run to straw, we should get a heavy crop of straw and probably but little grain, and moreover the plant would be unable to stand and ripen. In arriving at the best description of crop suited for the purpose, we cannot do better than consult the authorities in those places in which irrigation on a large scale has been carried on for many years. Thus the irrigators of Piedmont and Lombardy have found that marcite is the proper crop for cultivation. Now, this marcite is a mixture of Italian rye-grass and clover. The experience in this country also goes to show that Italian rye-grass, of all other crops, is the best suited for the purpose; indeed observation would lead one to conclude that grass in some form is the only crop generally admissible when we have to deal with large quantities of water; for if we take the distribution of rainfall in this country into consideration, we invariably find that those districts in which the largest rainfalls take place are grass-growing countries. Of all grasses up to the present time our experience shows that none have been found equal to Italian rye-grass, as what is required in the crop is that it shall be capable of growing rapidly when the elements of fertility are presented to it. Many grasses are naturally of slow growth, consequently are not so well suited for utilisation of sewage as a crop that grows more rapidly; but it must not be supposed that because a crop grows rapidly that that crop is naturally of an inferior quality; for we find that in the poorest pastures, where the rate of growth is the slowest, the quality of the herbage is the lowest, whereas on the other hand, in good and rich pastures the rate of growth is rapid, and the quality of grass is good; therefore as far as experience goes,

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quickness of growth would rather tend to establish the goodness of the crop.

Although it has been mentioned that wheat and other crops are unsuited for the direct application of sewage, yet they can be grown by sewage in an indirect manner; for it so happens that the constituents of grass and the constituents of sewage do not exactly correspond; but the excess not required is not lost, but is stored in the earth for use when required. It also happens that in the cultivation of rye-glass the plant dies out in three years if not regularly re-sown, and to get the best result it should be ploughed up every third year, and when it is ploughed up prior to being laid down again an intermediate crop may be taken without the application of sewage, thus using up the constituents of sewage that had been stored in the ground in previous years during the cultivation of the grass. Mangold-wurzel and beet have also been grown with sewage with great advantage.

Results of Utilisation.

The great result to be arrived at in the utilisation of sewage is the prevention of the fouling of rivers; in short in the purification of the sewage before being turned into any stream; and upon this head the results are most satisfactory.

In the case of Croydon, the sewage of that town, after being utilised, is positively purer than the water supplied by some of the metropolitan water companies.

In round numbers, the following figures will show the result:

Water supplied to towns . . .	21 gr.	per gallon
Sewage	39	„
Ditto after utilisation	23	„

and although there are but 2 gr. per gallon in excess in the sewage after purification of what there was originally in the water as supplied to the town, yet this excess must be reduced, for the drainage water represented a much larger volume of sewage; for in passing over the land a quantity of water is evaporated, which tends to condense the impurities that remain. If this result is contrasted with the results given by any process of precipitation of deodorisation, it will be at once seen how utterly fallacious it is to attempt to deodorise sewage. Indeed, there are few processes of precipitation that do not give a return per gallon of total constituents even greater than that possessed by the sewage before treatment, although the matter may be somewhat less objectionable in form; and moreover there is no process of precipitation that will precipitate ammonia directly from

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water, for the simple reason that there is no form in which ammonia is insoluble in water, and to precipitate any substance it is necessary that for the time it should be insoluble. The results of the application of sewage, in an agricultural sense, are also equally satisfactory; indeed it is surprising what enormous crops are produced under the influence of sewage, and the great difficulty is what to do with the crops; they grow so rapidly, and the yield is so large, that it upsets all the preconceived notions of farming. Indeed the only way in which sewage grass can be dealt with with certainty is the means of making it artificially into hay, and this the author has succeeded in doing, and is now about to submit the process to the test on a large scale. The Royal Commissioners who were appointed to inquire into the various matters appertaining to the utilisation of sewage have made a great number of experiments on the growth of grass with sewage, with the following results:

Quantity of ordinary meadow grass grown per acre at Rugby, being the average of three years:

	Non-sewaged.				Sewaged at the rate of 8000 tons per acre.				Sewaged at the rate of 6000 tons per acre.			
	Tns.	cwt.	qr.	lb.	Tns.	cwt.	qr.	lb.	Tns.	cwt.	qr.	lb.
Grass	9	6	0	24	22	5	2	7	30	6	2	6
Hay	3	0	3	4	5	1	3	5	5	15	1	23

Sewaged at the rate of 9000 tons per acre:

	Tns.	cwt.	qr.	lb.
Grass	32	12	0	15
Hay	6	9	1	24

The quantity of Italian rye-grass grown on the well-sewaged fields at South Norwood during the last year was over 50 tons to the acre; under ordinary circumstances, 40 tons to the acre may be reckoned upon; and as at Croydon this grass is worth 17s. to 20s. per ton on the farm, the value of an acre of produce may be estimated at from 30*l.* to 40*l.* As to the quality of sewaged grass, the Royal Commission have arrived at the following simple conclusion, after a great number of experiments: "That in both milk and increase, but especially milk, a given weight of animal was more productive when fed on unsewaged than sewaged grass, and that a given weight of fresh unsewaged grass was more productive than an equal weight of fresh sewaged grass; but that a given weight of dry or solid substance supplied in sewaged grass was more productive than an equal weight supplied unsewaged." Hence it would follow that hay made from sewaged grass has much better feeding and milk-producing qualities than hay made from unsewaged grass.

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The following figures will show the length of the respective crops of Italian rye-grass grown at South Norwood during last year:

	Length in inches.
1st crop	35
2nd do.	40
3rd do.	42
4th do.	32
5th do.	24
6th do.	14
	187 in., or 15 ft. 7 in.

Quantities of Sewage applicable to Land.

The quantity of sewage that may be applied with advantage to an irrigated area in the course of the year has been the subject of much controversy. Probably the fairest way to arrive at the amount of sewage that is required is by computing the total amount of the constituents of the crops cultivated, as it has been shown elsewhere that grass is the only crop that is fitted for the constant application of sewage. If we calculate the amount of sewage necessary to produce the 30, 40, or 50 tons per acre of grass, the amount that is annually grown on an irrigated area, we shall get a correct result. Baron Liebig has shown that if the soil is pure sand, and if the sewage is intended to supply all the constituents requisite for the growth of the plant, 2430 tons of sewage would be required to produce 4 tons of hay. If, however, the soil is rich in potash, so as to yield half the potash required by the plant, then 1225 tons will suffice to grow 4 tons of hay. As the amount of hay that would be produced on an irrigated field is much in excess of the 4 tons Baron Liebig assigns to it in his calculation, the amount of sewage he estimates that can be used on a given area will be proportionately greater. If it is considered desirable to apply as much sewage as will be sufficient for the growth of the plant without drawing on the resources of the soil, and as 1 ton of irrigated grass will make 4 cwt. of hay, it is obvious that to grow 30 tons of grass 3645 tons of sewage per acre per annum will be required, 40 tons of grass will require 4860 tons of sewage, and 50 tons of grass will require 6075 tons. If, however, the soil will provide half the potash required, then, to grow 30 tons of grass per acre, 1837 tons of sewage will be required; 40 tons of grass per acre, 2450 tons of sewage; and 50 tons of grass per acre, 3062 tons of sewage will be required. As 40 tons of grass per acre may be considered as easy of production on a properly regulated irrigated area, and as it would not be desirable to exhaust the soil of any of its constituents, 4860 tons per acre may be said to be the

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right amount of sewage required; that is, assuming that sewage is of the same strength as the dry-weather sewage of London. Now, as the dry-weather sewage of a population may be computed from the water supplies, it will be well to reduce the quantity of sewage applicable to an acre to the standard of the number of persons producing it, because as sewage becomes more diluted, a larger amount must be applied to get the same result. It may be taken as nearly correct, that the dry-weather flow of sewage of London is about equal to the supply of water, which at 30 gallons per head per day of the population would give 48·88 tons per annum, or, according to the previous calculation, an acre of ground will require the sewage of 100 persons in order to grow 40 tons of grass. This calculation entirely accords with our experience at Croydon; and it also agrees with the experiments made by the Sewage Commission, who arrived at the conclusion that 5000 tons of sewage per annum is the right amount to apply in order to get the greatest results.

Sanitary and Public Health.

As the experiments that have been made with regard to the utilisation of sewage by its direct application to land have become more or less successful, objections have been urged against the system by those who still cling to the exploded and unsuccessful system of deodorisation, or are too careless or indifferent to thoroughly investigate the subject for themselves. The last and probably the great stand that the opponents of the irrigation system now make is on the score of its being prejudicial to the health and lives of those living in the neighbourhood of the works. However much may be urged against the system, if the objections are not founded upon truth, they cannot stand. We all know how difficult it is to establish a new invention, for we are naturally averse to change, and an innovation arouses many a champion for the conflict who would otherwise have been content to go on quietly in the course he was treading, had it not been that his favourite ideas and notions were assailed, ideas and notions he may have long cherished, and which he cannot very willingly forego. Every invention or innovation that will not bear the closest and strictest investigation must fail when subjected to the scrutiny of its opponents; but if an invention is of any worth, the more its merits are discussed, the more will its latent virtues become apparent, until at length it will establish for itself a sure footing. Such will be the fate of the system of utilising sewage; the more it is discussed and criticised, the more apparent will its advantages become. Its simplicity will commend it, and the results it brings about will

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demand our attention. That sewage may be utilised without prejudicing the lives or the health of those living in the neighbourhood of the works has been proved by the past and present experience at Croydon and other places in the country; moreover, we have the testimony of the irrigators of Piedmont and Lombardy that irrigation, such as is practised in utilising sewage, can and is carried out to a large extent with great pecuniary benefit, and without any ill results on the public health. The malaria arising from swamps and such-like areas, produced by the periodic decay of vegetable matter, does not exist in utilisation of sewage, although it does exist in the system employed in the cultivation of rice: hence we must be careful in arriving at conclusions in districts in which irrigation is carried out to establish the description of irrigation practised. In Piedmont, Lombardy, Northern India, and other places, it is universally allowed that the cultivation of rice is certainly prejudicial to health, yet in these same countries it is by no means established that the system of irrigation as practised in the utilisation of sewage is detrimental to public health; indeed notwithstanding the unfavourable nature of the climate, it is considered that the system is and can be carried out without prejudice to the public health. Hence the laws affecting the subject of irrigation in Lombardy prohibit the establishment of rice irrigation within five miles of the capital of the kingdom, and three miles from first-class towns; but the same laws allow the cultivation of Italian rye-grass and clover by irrigation within 1100 yards of the capital, or within 530 yards of first-class communes; and moreover so favourably is this system of irrigation looked upon, that while the laws relating to the irrigation of rice are maintained in full force, the laws relating to the irrigation of marcite—Italian rye-grass and clover—are allowed to lapse, and persons do now carry on this description of cultivation without let or hindrance of any kind. Captain Baird Smith, in his work on Italian irrigation, gives the following opinion, which is of value as bearing on the question of irrigation with sewage: "I may briefly give some details which seem to me to justify the non-interference of the Government in the case of marcite and common meadow irrigation. Why indeed the latter should have ever been interfered with at all seems to me difficult to understand. The meadows are watered once a fortnight usually. The quantity of water thrown upon them is equal in its effects to a heavy shower of rain, but scarcely more. Means of efficient drainage are invariably established under the best guarantees, the guarantee of self-interest in the valuable surplus waters or colature; stagnation of water, even for a very limited time, is rigidly guarded against as an imperfection most injurious to the crop. With such provisions

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and precautions, it is impossible to conceive irrigation can be mischievous to health, and the idea that it is so seems to be universally abandoned."

It must be recollected, in a field irrigated with sewage that there is no tendency to putrefaction: 1st, because matters only in solution should be permitted to flow over the land, and any tendency to gaseous exhalations is instantaneously stopped by the absorbing properties of the soil; 2nd, the state of vegetation is always one of vigorous growth, there is consequently not any tendency for the crop to decay. From the statistical returns of Lombardy, it appears that the Government are fully justified in refraining from any interference with the process of irrigation, as carried on in the cultivation of marcite, or in common meadows, as public health has been found to be so little affected by it. In the neighbourhood of Milan, marcite is cultivated very largely with the sewage of that city, but without any ill-result to its inhabitants; but at Croydon it has been said that the result has been found prejudicial to health—upon what occasion it would be difficult to say. It may be said that the adversaries of the system wished it to be so, and the thought became realised. Croydon was the first town to adopt and carry out the Public Health Act of 1848; it was the first town to adopt the tubular-pipe system of drainage—a system that has completely revolutionised the whole system of drainage, throughout the country; and Croydon was the first town since the introduction of the Public Health Act to adopt the process of utilising its sewage after giving every conceivable plan of deodorisation a fair and impartial trial.

Although Croydon has stood out foremost in furthering the cause of sanitary science, its very prominence has brought upon it the attacks of all those who did not agree with the systems introduced, and they made Croydon the battle-field to determine the questions at issue. Pipe sewers were attacked and condemned, yet in spite of the condemnation passed on them year by year, greater numbers are manufactured, and the system is nearly universally adopted. It cannot be overlooked that as Croydon was the pioneer in the track in which many towns have followed, and in which they must still continue to follow, of necessity many imperfections must exist in the early works; and this circumstance, while it has been fortunate for the country at large, has been unfortunate for Croydon itself, other towns having profited, and still profiting, by its experience. One of the great errors committed in the early works was the too small size of some of the main sewers. Another was the want of sufficient ventilation of the sewers, and these two causes, acting in concert at a recent

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period, tended to conduce to an unhealthy state of things, which the opponents of utilisation at once, and without a moment's reflection, ascribed to the irrigation areas; but the districts affected told their own tale as to the cause, as they were the highest and best in the town, and at the heads of the sewers, and were the farthest removed from the irrigation fields, being upwards of two miles from the nearest irrigation area; and, moreover, during the prevalence of the disorder referred to, the wind was blowing from a direction opposite to that which would have had any tendency to have wafted any vapour or odour towards the town.

Again, the most careful inquiry was instituted in order to ascertain if the inhabitants, living in the immediate neighbourhood of the irrigation areas, suffered at all from any particular disease, and the result showed most conclusively that the whole population in the vicinity of the irrigation works was perfectly healthy; in fact, the only case of disease that could be found was an isolated case of whooping-cough. At South Norwood, irrigation works have been established eighteen months. These are very important works, for they may be said to be a test upon the health of the neighbourhood, as they are within a few hundred yards of the town; but the following Tables of mortality in Norwood will show most conclusively that never has Norwood had such a favourable rate of mortality as during the last year, or the year in which its sewage has been utilised; and what is more remarkable is this, that Croydon has had generally to complain of its mortality being swelled by the mortality of Norwood; but during the last year the tables have been reversed, and the mortality of Norwood had a tendency to lighten the average rate of mortality of Croydon, instead of, as in former years, to be a burden to it.

MORTALITY TABLES.

Dates.	Town districts of England.	Croydon parish.	Norwood only.
1860	...	16·63	18·35
1861	...	18·00	No. taken out
1862	...	18·48	,,
1863	...	20·49	21·84
1864	...	20·97	...
1865	25·43	21·26	18·17*
1866	26·39	20·04	15·13*

* Years of utilisation of sewage.

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Schedule of Towns in which the Sewage is more or less utilised.

Names of Places.	Population.	Number of gallons per day.	Acres under irrigation.
Aldershott camp	14,000	...	250
Alwick, Cannongate.....	6,000	300,000	350 to 400
Bingley, Yorkshire	"	"	30 to 40
Birmingham	30,030	15,000,000	130
Braintree	50,000	"	20
Bury St. Edmunds	"	Experimenting	"
Carlisle.....	21,000	843,000	80
Cheltenham	36,000	1,000,000	120
Croydon	"	Two to five millions	360
Edinburgh	180,000	"	"
Hopwood	2,200	"	6
Leek.....	10,500	400,000	130
Mansfield	10,000	"	400
Melton Mowbray.....	"	Experimenting	"
Milverton.....	1,400	4,000	4
Mold.....	4,000	6,000	6
Nottingham	"	Experimenting	"
Oswestry	"	Proposed to irrigate	300
Rugby	8,000	80,000 to 200,000	400 to 500
St. Thomas, Exeter.....	...	Proposed to irrigate	150
Swaffham	2,000	"	5
Tavistock	8,000	Proposed to irrigate	90
Uckfield	1,200	"	4
Worthing	6,000	700,000	40

DISCUSSION.

Mr. H. P. Stephenson quite agreed with the author as to the value of sewage, which he used himself for the production of flowers and vegetables. Perhaps Mr. Latham had spoken a little too strongly of Croydon as the pioneer in sewage. Great errors had been committed there in the early stage of the pipe-sewage system, and in many instances the sizes of the pipes were really absurd. While engaged with the late Mr. William Ranger, of the Board of Health, the whole of the sewage of Darlington was designed, under his directions, to flow into an outfall pipe. He had no doubt that it was owing to the prevalence of small-pipe sewers that what was known in Croydon as the black fever had visited the town. He did not think that Mr. Latham was right in attributing the visitation of last year to the higher parts of the district. It generally took the lower parts, and he viewed it with a certain amount of anxiety, on account of the large masses of sewage which were thrown upon

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extended areas. Probably Mr. Latham was correct in attributing the fever to the improper ventilation of the sewers.

Mr. MORRIS asked Mr. Latham if he could furnish the Society with a detailed chemical analysis of the water supplied to the town, and of the sewage water after it passed from the land in a deodorised state? Although it was stated that twenty-one grains per gallon was the amount of the impurity in the water supplied to the inhabitants, and twenty-three grains per gallon the amount of impurity in the water as it passed off from the trenches after irrigating the land, that gave a very faint notion of what the chemical character of the purification was.

Mr. OLRICK said he was disappointed in the paper, not as regarded its merits, but its subject, as last year Mr. Latham promised a paper on the filtration of water, and when he (Mr. Olrick) heard the announcement that Mr. Latham was going to read a paper he naturally thought it would be on pure water, instead of which it was on dirty water. At the early stages of the drainage of Croydon there were mistakes made which looked very curious at the present day, and were certainly curious samples of amateur sewage engineering. The first crockery pipes that were laid, broke and leaked; then, as the paper stated, they were replaced by pipes made of thin plastic clay or puddle, which were also inefficient. Then a thick tube of brickwork was put round the clay. This plan succeeded in carrying away the sewage, but it also succeeded in poisoning the river Wandle, the exhalations of which were very injurious to the town. The fish in the river were destroyed, and the surrounding vegetation was much deteriorated. The soil in the neighbourhood became very poor, simply for want of manure. Many cases of disease were directly traced to the accumulation of refuse, the contamination of the river by the sewage, breathing foul air, and drinking foul water. That the contamination of rivers and wells was very injurious could be seen from the terrible effect produced by certain pumps in London during the last visitation of the cholera. It was well known that the water from the pumps in London was used by the inhabitants living around them, and among some of these groups of people the mortality was so great that it could not be ascribed to anything but the impurity of the water obtained from the pumps. A lady residing in Soho, where the mortality was very great, removed to a very healthy district, but she continued to send every morning to the Soho pump for a supply of water; and the consequence was that she was attacked by cholera, and hers was the only case of the disease in the neighbourhood to which she had removed. At Oxford, Kingston, and Leicester the sewage was deodorised by means of lime, which purifies the water and pre-

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vents the sewage being a nuisance, and there are now plenty of fish and fruit which were previously poisoned; but the sewage was of no commercial value as manure on account of its containing lime. What system of disposing of sewage would be applicable to London, was a question difficult to answer. There were not many places which possessed such facilities for the application of sewage to the purposes of irrigation as Croydon and Edinburgh, for no pumps were required to assist in the distribution. At Rugby, Waterford, and Carlisle it was dealt with in the same way as at Croydon; but pumps had to be used, and a large amount of capital had been invested in constructing the necessary machinery. A very important step had been taken as to the sewage of London, in the construction of the main drainage works; but the great point to be settled was the utilisation of the sewage after being conveyed to the outfall; for at whatever state of the tide the sewage might be discharged into the river, no doubt a portion of it would be carried back towards the metropolis. It might be pumped to some elevation, and then run down by gravitation, and be supplied to the farms of Essex, where no doubt it would be very acceptable. While London had spent three millions in getting rid of its sewage, Oxford and Kingston continued to discharge their sewage into the Thames, and thus fouled its water before it reached London. The commercial part of the question of sewage irrigation would no doubt always be present to the mind of the farmer. To dispose of the sewage of an immense city like London it might be necessary at first to give it away for use on the land until the farmers became thoroughly aware of its value.

Mr. Reeve said he believed that the last epidemic at Croydon was attributable to the drains not being trapped, and their ventilation through rain-water pipes.

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April 16*th*, 1866.

A. WILLIAMS IN THE CHAIR.

ON THE UTILISATION OF SEWAGE.

BY BALDWIN LATHAM.

ADJOURNED DISCUSSION.

Mr. BALDWIN LATHAM commenced the discussion by giving a short history of drainage, stating that considerable care seemed to have been exercised by the founders of the ancient cities of the world in order to ensure their effectual and efficient drainage. Sewers of large size were constructed, evidently to serve the purpose of carrying away all filth from within the cities themselves, and very probably also as a means for carrying on an offensive warfare against a besieging foe. Carthage and Alexandria were sewered. All the cities founded by the Romans were sewered and well supplied with water, but it does not appear that the refuse or drainage was used or turned to any useful account, although it is improbable that in a country like Egypt, in which irrigation appears to have been practised long before the dawn of history, that they would permit the waters flowing from their cities to go to waste. In China, irrigation has been practised from remote periods, and the fæcal matter of the people seems to have been rigidly preserved and generally used in connexion with the system of irrigation, although we have no example of a town or city having been sewered and its sewage directly applied to the land. As our sanitary science in a great measure is based upon the principles propounded in the judicial law, it will be well to inquire into the history of sanitary measures among the Jews, in order to ascertain the precise measures that were adopted by that nation for the disposal of fæcal matter, and also to throw some light on the question of the disposal of sewage. So long as the Jews as a nation lived in tents and had constant opportunity of moving about from place to place, they had no difficulty of dealing with fæcal matter; hence we learn it was deposited in the ground, or, in other words, was deodorised by the admixture with earth. When the Jews no longer lived in tents, but began to inhabit houses in cities and towns, a new state of things was brought about, and

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the same facilities could not be afforded them of dealing with fæcal matter as existed in their more primitive mode of life; but yet, in order to carry out their religious obligations and ordinances, it was absolutely necessary that they should adopt some method that must have been successful in disposing of the sewage of their towns.

From the light that within the last few years has been thrown by the discoveries of men of deep research into the ancient condition of Jerusalem, we learn that that famous city had an abundant supply of water and was well provided with capacious sewers, and, moreover, that the sewage was utilised.

From Dr. Whitty's excellent work on the water supply and sewerage of Jerusalem we learn that "Eusebius, who was a native of Palestine and died there about the year 340," "thus quotes Timocrates, the surveyor of Syria, when writing of Jerusalem:" "The whole city flowed with water, so that even the gardens were irrigated by those overflowing waters out of the city."

Dr. Whitty, further quoting from a paper by the Rev. George Williams, B.D., Senior Fellow of King's College, Cambridge, upon recent discoveries of Dr. Pierotti: "The situation of the Temple appears to be fixed beyond all possibility of doubt by the recent discovery by Signor Pierotti of the complete water system connected with the Hebrew Temple still existing as entire as when it was in daily use during the period of the Jewish Commonwealth. The perfect preservation of this complicated system of aqueducts, drains, and reservoirs is owing to the fact that they are excavated in the solid rock, and therefore have not been affected by the demolition of the structures above, except so far as they may have become partially blocked up by the accidental falling in of the *débris* of the ruined buildings."

"Had history been silent on the subject, yet we should have been forced to conclude that there was a very complete system of sewerage connected with the Temple, introducing a large quantity of water to dilute the blood which would otherwise have a tendency to coagulate, and carrying off the blood and offal from the sacred precincts." "This, history tells us, was actually the case; and the supply of water was so managed as to flush the whole court, and carry off the blood of the numerous sacrifices." The drains leading from the Temple, and probably from the city, discharged themselves into a pit, "which is now called the Fountain of the Virgin," and which communicates, by means of a channel in the rock, with another pit now traditionally called the Pool of Siloam, but which, there is every evidence to show, is not the true Pool of Siloam.

"It is a necessary consequence of the Fountain of the Virgin

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having been originally a cesspool, and, if that be admitted a fact incapable of being controverted that the Pool of Siloam (now so called) was likewise a cesspool, formed for the purpose of receiving the liquor from the upper cesspool in order that the manure in it might become sufficiently desiccated to be in a fit state for removal by the gardeners who purchased it, and that the tunnelled conduit was that through which the moisture was drained off into the lower cesspool or liquid-manure tank." We find from the Mishna: "There was a certain cave beneath the altar whereby filth and uncleanness were carried down into the Valley of Kidron, and the gardeners paid so much money as would purchase a trespass-offering for the privilege of fertilising their gardens with it." The liquid matter, after leaving the traditionary Pool of Siloam, was then used, as it is at the present day, for the purpose of irrigating the king's gardens. From this description of the outfall works of the sewerage of ancient Jerusalem we learn that the sewage was collected in tanks, the solid matter was removed from it and sold, and the liquid was afterwards used for the purpose of irrigation, which plan is identical with the plan in operation in Croydon at the present time. In the latter part of the twelfth century we learn that the system of sewers in operation in Milan was greatly improved and extended, and the sewage was collected and discharged into the Vettabia and was afterwards used for irrigation, and has been continued to be used, with great success, up to the present day.

On the meadows of Edinburgh sewage has been applied for upwards of a century with great pecuniary advantages; indeed, worthless land has been turned into the most fruitful, thus effectually showing that the application of sewage for unlimited periods can be carried on without injuring good land, as has been suggested in the case of some of the land under treatment at Rugby, because it must be quite clear that if the application of sewage has a tendency to improve the poorest land, it is impossible for it to injure good land: so that if any land at Rugby was injured, as it was supposed to be, by the application of sewage, it is due to some error in the system adopted, and very probably the error lies in the limited amount of fertilising matter supplied to the land, as the influence of a moderate application of water to land has no exhausting effect on the soil (which, by the way, is exactly the result you would expect), because if a given amount of produce is annually taken for land, and an equivalent in fertilising matter is not supplied under the stimulating effects of water, you naturally must expect that the land will be impoverished.

At Croydon, the local board commenced its public duties in

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September, 1849, and forthwith commenced to organise a scheme for the drainage and water supply of their district. Professor Donaldson was the first person consulted on the subject, and Mr. J. Cox, the surveyor, was afterwards associated with him; and on the 27th of November, 1849, the joint report of Messrs. Donaldson and Cox was received. In January, 1850, an application was made to the late General Board of Health for sanction to borrow the money required for the works. Some delay occurred in procuring the sanction, as plans, details, and estimates were required to be submitted to the General Board's inspector; but on the 5th of February, 1850, the General Board appointed Mr. Ranger, at the request of the local board, as their inspector, and on the 16th of April, 1850, Mr. Ranger, acting as inspector, required the local board to determine upon the method intended to be adopted to get "*rid of the sewage;*" but as nothing seems to have been settled upon this point, and, after a conference with the local board, Mr. Ranger, the inspecting engineer for the General Board of Health, was appointed consulting engineer by the Croydon local board, and shortly afterwards the General Board sanctioned the borrowing, on the part of the town of Croydon, the sum of 32,965*l.* for the purpose of drainage and water supply. Soon after the drainage was proposed to be carried out, the local board were inundated with the offers of different persons to take the sewage from them. Some of these persons proposed to take the sewage for the purpose of irrigating land, while others proposed to manufacture it into manure. The first actual example of the application of sewage in Croydon occurred before the works of drainage were completed, and it arose from the condition of an offensive ditch which the local board were called on to remedy; but as there was no mode of dealing with it, C. W. Johnson, Esq., F.R.S., the then and the present chairman of the local board, proposed to take this offensive matter on to his own ground, with what result the numerous valuable experiments he has made, and which have been before made public, bear testimony. The plan proposed by Mr. Ranger for dealing with and purifying the sewage was by the construction of filters at the outfalls, in which the sewage was to be filtered. The sewage water, even at this period, was used at more than one outfall for the purposes of irrigation; but it did not answer, and every person who took it was only too glad to give it up, and, in some cases, they even sought compensation for the injury done to their land.

It was not long before the system of filtering was found to be a great nuisance, and the board found themselves involved in several expensive lawsuits. When every conceivable process

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was tried for purifying the sewage, among others I may mention the filtration through charcoal, Higgs's patent lime process, treatment with carbolic acid and perchloride of iron, besides many others; but no plan was found to be successful until large areas of land were taken, and, what is of more importance, they were first fitted by proper and suitable formation for the reception of the sewage.

Mr. Scott said that it was quite evident that engineering skill in the utilisation of sewage was not keeping pace with the wants of towns or the sanitary requirements of the country. There were many reasons for this. The watercloset system was increasing at such a rate, and producing a nuisance of such gigantic proportions, that time did not permit the devising of engineering plans for its removal and the maturing of agricultural arrangements for its application. At Edinburgh, where irrigation had made barren lands fruitful, no objection could be brought against its application; but, as applied to ordinary lands, the case was different. Such lands would be injured and impoverished unless supplied with those ingredients which the sewage itself did not contain. With regard to town sewage, one difficulty seemed to be the variety of its constitution in different towns. Where there was a domiciliary population the excreta of the town was easily estimated; but in the case of towns where there were manufacturing premises, dye-works, bleach-works, chemical-works, smelting-works, and works producing all kinds of poisonous refuse, the sewage produced a kind of petrification or ossification in the roots of plants, and hence the elements of fertility in the sewage, which were held either in solution or suspension, and did not act upon the vegetation. It was clear, therefore, that there could be no uniformity in utilising sewage, because very few towns produced the same quality. At the same time it was impossible that the pollution of rivers could be allowed to go much further. He believed, as an agriculturist, that in many cases town sewage could not be profitably applied. One plan of applying it profitably consisted in intercepting it on the higher ground, and allowing it to flow by gravitation over meadow land. It was diverted by very simple contrivances to the various parts which required it. There was at present no power in corporations to raise or expend funds for the utilisation of sewage, and hence it generally flowed into the nearest watercourses and ditches, which were thereby rendered quite impossible with safety. If requisite powers were granted to corporations and governing bodies in towns, and a Government officer appointed to inspect and confirm or alter the plans of any works proposed by such governing bodies, remedies would be found in every

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town. In many cases the utilisation would be a source of profit; in others it would entail a loss; but in all cases it would ensure safety to health. On the banks of the Ouse, near Buckingham, he had irrigated nearly 200 acres of land by a system of upward filtration, the river being supplied below the surface. That system was applicable where towns lay on a level with the surrounding lands.

Mr. Rawlinson, C.B., said he had had the honour of acting for eight years as a member of a Royal Commission appointed especially to inquire into the utilisation of town sewage. He was also a member of a Royal Commission which had been inquiring into the means of preventing the pollution of rivers; the first report of which on the valley of the Thames was presented to Parliament. He had examined all the important places in England where river pollutions took place, as also many places where sewage had been applied to purposes of agriculture, and, in his opinion, the question of the utilisation of sewage lay at the root of the progress of civilisation. Some men were advocating the abandonment of waterclosets and sewers, because rivers were so fearfully polluted by them, and it had been gravely proposed to return to a use of cesspools. Then, in order to deal with effete refuse, systems of deposition and of artificial drying had been set up and even patented. Some of the plans which had been put forward by patentees would, however, if detailed, only serve to raise a smile. His own opinion was that the method which would secure the greatest amount of health to the greater number of people in this populous country ought to be considered the best method. If it were found that the fouling of the rivers by sewage was less injurious to health than having no sewers at all, he thought that, as philanthropists, they must decide on fouling rivers, but he did not believe that it was necessary to go on fouling rivers. He thought he could see a way out of the difficulty, and very few men in this country had practically assisted more to clear up this subject than Mr. Latham, who had read the paper now under discussion. In his (Mr. Rawlinson's) opinion, the question was decided as regarded Croydon. That was essentially a watercloseted town. The town was drained on the tubular system; the water supply was adequate, and the effete matter was delivered at the outfall within a very short time of its entering the drains and sewers. That was a very important thing to be taken into consideration, because fresh sewage was comparatively innocuous; but sewage retained in a cesspool until it was putrid generated the most deadly gases. Paris, with all its apparent cleanliness, and with all its vast expenditure on subways, remained a city of cesspools. Within the last summer cholera had been prevalent in Paris,

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and the health of that city was below the health of London. During the last twenty years in the metropolis of Great Britain waterclosets had been substituted for cesspools by thousands, even in the worst parts of London, such as Mile-end, West Ham, Bermondsey, and Lambeth, and although the river Thames had been increasingly fouled year by year with the increasing population, the mortality had been steadily reduced. That was really a question deserving attention. He did not, for one moment, advocate the pollution of the Thames. A gigantic and most costly work had been commenced for the purpose of doing away with that pollution, but he thought that a mistake had been made at the great sewers' outlets. He would have had none of those large underground cesspools, but would have expended the money which they cost in taking the sewage ten or fifteen miles farther down. It was stated that a company had entered into an arrangement to take and utilise the sewage of London on the northern side. And he understood that the Metropolitan Board were in treaty with some parties to take the sewage on the southern side and utilise it also. If those projects were carried out, and the example of Croydon were followed, the results must be beneficial. The schemes for utilisation had to meet with many prejudices. Medical men came forward and gravely stated that there was an evaporation of miasma from the surface of lands irrigated, which produced a type of disease similar to that generated in malarious countries. Fortunately these opinions were contradicted by other medical men of equal eminence. His own opinion was that where the application took place with proper precautions, and where the area of the land was sufficient, irrigation might be carried on without causing a nuisance to anybody. Complaints had been made with regard to the works at Croydon, that the effluent water did not at all times come away bright and clear, but these complaints generally referred to Sunday, when the men were probably not working with the same regularity as on other days. And there were more of such complaints made in the summer than in the winter. The reason of that was, that in summer the green crops were growing rapidly, and a large number of men, horses, and carts went on to the ground and stirred up the surface. With regard to the question of town sewage he did not agree with Mr. Menzies in the opinion that sewage should never be mixed with the surface water; this was, however, a question of detail which could not be explained in a few sentences. It had been said that in some cases sewage injured land; and he believed it was a fact, that if sewage was turned on a rich piece of old meadow land for a time, and were then discontinued, that land would be spoiled for a time as meadow land. That was not the way,

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however, to apply sewage; but if it were used for Italian rye-grass, they would get crops which would almost bewilder some persons. In Worthing, some of the crops last year were fifty tons to the acre, the first of the crops being twenty tons an acre. He believed that some form of legislation should take place to compel local boards to do their duty, and to apply sewage to land so that it shall be cleansed by the land before the water was allowed to flow into the rivers, whether that application paid or not. It should be done as a matter of trade protection, as also to secure comfort and health. From wide experience he believed that the greatest nuisance in the cotton district was the cesspit system. If any one would traverse a district which was in the hands of the nightmen he would not want to traverse it a second time. The mortality was very high in those parts. Typhoid and typhus fevers were prevalent there, and these were essentially adult diseases; they attacked heads of families. The "bread-winner" being often taken away, the wife and children became chargeable to the parish. As a matter of saving rates, therefore, it would be a great economy to adopt measures to lower the rate of mortality. Manchester and Liverpool were crowded by cesspits, and were traversed by miles of sewers defectively ventilated. In London, the sewers were ventilated over the whole area, but direct from sewer to street: this was a very clumsy plan. There was a shaft direct from the sewer to the open air. The grating was directly over the sewer; the gases of decomposition, consequently, came direct into the air of the street, and road grit fell upon the invert of the sewer, blocking the flow of sewage. He (Mr. Rawlinson) had ventilated many sewers, but he had put a side chamber and an intercepting box of charcoal. The gas had to pass through the charcoal, and the road grit was kept off the invert of the sewer. He would not, however, say one word against the ventilation of the sewers of London if it would tend to retard it. Open, full, and free ventilation was of the utmost importance. Side chambers and charcoal screens could be added to the shafts now in use. Ventilation was the salvation of the London sewers. If the sewers of Liverpool and Manchester were only ventilated as fully as in London, and even as rudely, the mortality in those towns would not be so great as at present. With regard to the application of sewage, it was the opinion of many men, well qualified to judge, that there is no class of land to which it could not be applied. There was a notion prevalent that clay land was not capable of utilising sewage; but the truth was that clay land was, probably, the best of all land for the purpose, because the clay prevented the contamination of wells. Where there was a porous subsoil, care must be taken that there were no wells

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adjacent from which persons drew water, or there would be a risk of poisoning them. The brightness of water was no guarantee of its purity.

Mr. FISHER said that it was not one branch of the community alone which would be benefited by the utilisation of sewage. It would benefit capitalists, landowners, agriculturists, and engineers, and therefore it was a study for them all. He had carried out a system at Plumstead somewhat similar to that which Mr. Latham had adopted at Croydon. Before the metropolitan sewers were brought into the district of Plumstead, the sewage was conveyed to the ditches in order to be disposed of. The Government and also the farmers greatly objected to such a course, and therefore, in order to render the sewage as innocuous as possible, filtering beds were put between the sewers and the ditches. The water came off pure in colour; but it was not harmless. The medium used for the filtration was turf. Some of the sewage came from a brewery; it seemed to be of a sour character, and produced a greater amount of smell than any other kind of sewage. At the outlet of the metropolitan sewer the river was fouled very much indeed, and the smell of the water was very bad. The mortality of the district of Woolwich and Plumstead was, however, rather favourable than otherwise. It might have been expected that the mortality would be increased in that district on account of the sewage works being placed so near; but the result showed that the removal of the sewage of the district was a very great benefit to health.

Mr. MORRIS wished to ask Mr. Latham whether all the matter in the sewage was taken off by the land, or whether there was some chemical action between the oxygen of the atmosphere contained in the land and the sewage water, by means of which the matter was oxidised and rendered innocuous. He had in his possession a pamphlet by Mr. Spencer, in which he stated that he could deodorise sewage and remove the organic matter from it by means of a magnetic carburet of iron, which caused the oxygen to assume the form of ozone, and thus decompose the organic matter. The question was, whether something of this sort occurred when the sewage passed over the land, or whether the land merely retained the sewage matter, causing nothing but the clear water to run off? Perhaps Mr. Rawlinson could give some information as to the use of the carburet of iron.

Mr. RAWLINSON said, with regard to the filtration of sewage as ordinarily understood, that in his opinion it was impossible to effect it except by passing the sewage through land. They might separate the flocculent matter and take out the solid residuum in a very simple manner; but to alter the chemical constitution

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of sewage it appeared that the passage through land was absolutely necessary. When sand, or charcoal, or carbide of iron had been used, it had been found practically, by chemical analysis, that the sewage passed away with nearly all the same salts as it contained before the process.

Mr. DONKIN wished to know what description of valve was used by Mr. Latham.

Mr. CARGILL said, that it seemed that the application of sewage to land was beneficial in some cases, but had the reverse effect in others. The application of sewage, with a merely sanitary object, would never be taken up by contractors or speculators unless it could be profitably carried out. No doubt the land had been impoverished by an injudicious system of culture, and it was questionable whether, if farming had been carried on scientifically from the earliest times, the land would have required manure at all. With regard to the manner in which the irrigation had been effected at Croydon, he believed that it had been shown that, although the solid matter of the sewage was deposited, the phosphates or phosphoric acid which it contained flowed off with the water. On Professor Liebig's assumption, that would be a very important consideration in certain crops, because it was settled that the most important constituents in the production of plants were the nitrogenous and the mineral constituents, of the latter of which the phosphates formed a portion. One element bearing on the economy of the application of sewage was the cost of transport. It was probable that out of every ton of sewage which a farmer took to his land, nine-tenths were of no use to him. In the county of Down, in the north of Ireland, where flax was cultivated to a very large extent, the water in which the flax was steeped made a very good manure; but the farmers rarely applied it for that purpose. He wished to know what fall Mr. Latham generally gave to his sewers.

Mr. REEVE said, he believed there were very few instances of such land as the last speaker had described, in which manure was unnecessary. There were some lands in Yorkshire and in the fens of Lincolnshire where the fertilising matter was very abundant, which seemed almost inexhaustible; but such instances were very rare. As to the ventilation of sewers, it was generally carried out in a very offensive manner, and the smell from the street gulleys was often very bad.

Mr. RAWLINSON said, that if street gulleys were blocked up and the gas were not allowed to escape, it would be inevitably forced into the houses, and there it might be deadly. It was found that foul smells in the open air did not so often produce evil effects. Partially oxidised gases might be breathed in the open air with comparative impunity, whilst the same gases

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breathed in confined rooms would be capable of lowering the system and ultimately produce disease. If he had his way, every sewer in London should be ventilated so as to pass its gases through charcoal.

Mr. P. F. NURSEY observed that most of the large manufactories added, in a greater or less degree, to the accumulation of gases in sewers. The Aërated Bread Company, for instance, employed a mixture of whiting and oil of vitriol for the generation of carbonic acid used in the vesiculation of the bread. When that mixture had ceased to evolve the gas in sufficient quantity for their purpose, it was discharged into the sewer, where it continued to give off carbonic acid in such volume as to render the atmosphere unwholesome. About half a ton of this refuse was let into the sewer at a time, and there was reason to believe that it was not only evolving carbonic acid, but from its acid nature was causing the escape of sulphuretted hydrogen from the sewer mud. A few months since, some workmen were nearly suffocated in the Blackman-street sewer, near the aërated bread bakery, and the accident doubtless arose from the cause just indicated. That pointed to the necessity of adopting means whereby the discharge of noxious matters into the public sewers might be regulated. Restrictions should be placed on the discharge of all manufacturing refuse into the sewers. The accident in the Blackman-street sewer led to proceedings being taken by the Metropolitan Board of Works against the Aërated Bread Company, which ended in the Company making arrangements to supersede chalk for obtaining carbonic acid gas, by the use of sugar. The process was founded upon one in use in America for a similar purpose, in which grapes were employed.

Mr. JENSEN said there were other ways of producing carbonic acid gas, besides that which the Aërated Bread Company had been using. They used whiting and sulphuric acid. Some eminent medical men had expressed an opinion that it was highly improbable that the two men who lost their lives in the sewers some time ago were suffocated by carbonic acid gas generated by the Aërated Bread Company. He wished to ask whether Mr. Latham ever tried to utilise the refuse from soda-water manufactories, or other works which used carbonic acid in large quantities. He (Mr. Jensen) had heard that persons went to soda-water manufactories from long distances, and in some instances paid for the refuse.

Mr. P. F. NURSEY asked whether the Aërated Bread Company still continued their original process, or whether they had adopted the method of obtaining carbonic acid gas from sugar or molasses?

Mr. JENSEN said they did, but they had provided a large

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tank for the reception of the waste liquor, instead of discharging it direct into the sewer. They expected that persons would fetch it away to utilise it: he had heard of one party being in treaty for it.

Mr. REEVE said that immediately the Aërated Bread Company's refuse liquor entered the sewer, it generated another gas almost to the same extent as the original gas. That refuse applied by itself to light land was perfectly useless.

Mr. RAWLINSON, in reply to an inquiry, stated that the cost of the charcoal-box would be about 7s. 6d., and the cost of the side shaft would be about 2*l.* or 3*l.* He believed that if public opinion and scientific inquiry were directed to the subject of the fouling of rivers and the utilisation of sewage, it would be backed up by legislation. He contended that the same course should be pursued by the Government in reference to sewage and the pollution of rivers as was adopted in reference to the fumes from alkali-works and the refuse from gas-works.

Mr. MORRIS said that at Woolwich the sewers were ventilated through being connected with a high chimney-shaft in the dockyard.

Mr. FISHER said that at Plumstead the sewers were to be ventilated by means of shafts about fifty feet high.

Mr. RAWLINSON said that if chimney or other tall shafts were used for the ventilation of sewers, they would have to be multiplied to an alarming extent. He would not say abolish such shafts; but let the sewers be ventilated in other respects, and the openings just as numerous as if the shafts were not used.

Mr. P. F. NURSEY remarked that the ventilation of sewers, by drawing off the gases by furnace shafts, was generally considered a novelty, but he believed it had been adopted on the Continent for some years past with considerable success.

Mr. LATHAM, in replying to the discussion, said there was little or nothing left for him to say. He had been asked at the last meeting for some further particulars as to the analysis of the sewage water at Croydon, when it passed off the land, and he stated that it contained 20½ grains of inorganic constituents and 2½ of organic, making 23 grains total, which was less than is contained in the water supplied by some of the London Water Companies. The town water at Croydon contained over a grain of organic matter, and the sewage as it flowed to the land contained 39 grains of total constituents. At Croydon the fall of the sewers varied from about 1 in 50 to nothing. Some of the sewers were on a dead level. No valves were used or required in distributing the Croydon sewage. With regard to the ventilation of sewers, that was a matter that had been entirely ignored or neglected at Croydon and in many other towns; but

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the Croydon sewers are now being properly ventilated, and the good effects have already been experienced. The plan adopted provides for the escaping gas to pass over charcoal; each ventilator fixed cost about 45s. As a criterion of the value of sewage, he might state that the Croydon local board had received an offer from their tenant at South Norwood to pay the board the entire cost of the construction of the works and outfall sewers, which cost about 3000*l.*, and also to pay 200*l.* per annum, as the rent of 37 acres under irrigation for a term of twelve years. Mr. Morris had asked whether the atmosphere had not some effect in purifying the sewage in passing over the land. It was well known that all porous substances had more or less power in attracting oxygen; but whether the earth on that account had any effect in purifying the sewage, it was difficult to say. He believed that the process of purification was mostly due to the property the ground had for attracting fertilising matter. Clay soil was more effective in purifying sewage than sandy soil, whereas it contained less interstitial space than sandy soil, and consequently held less air and oxygen. He thought that oxygen performed no very great part in the work, or certain matters would be oxydised and free carbonic acid would be eliminated; and then we should naturally expect that the free carbonic acid would combine with the constituents of the soil, and give a much larger per-centage of inorganic constituents than found in the effluent water. One gentleman had said that soils had not an affinity for phosphoric acid. He (Mr. Latham) believed that was a total mistake, and that most soils had an affinity for phosphoric acid, and the great outcry against sewage was that it did not contain sufficient phosphoric acid. Again, it had been said that there was some land so rich that it did not require manure, but he had never met with land of that description. A question had been raised as to the disposal of refuse water from soda-water and mineral-water manufactories. He had found at Croydon that the matter let out from such works had stopped up the private drains of the manufactories, by forming a kind of concrete in them. The manufactories diluted the matter as much as possible, and it escaped; but he believed that matter would be useful, and might be converted profitably into plaster of paris. He quite agreed with what Mr. Rawlinson had said about the suitability of rye-grass for the application of sewage. He believed that that was a production specially marked out by Providence for that particular purpose. It must not be supposed that because sewage destroyed meadow grass, it injured the land. The whole result of sewage irrigation showed most conclusively that sewage might be utilised with profit and advantage. He believed that as a class farmers were very far behind the age.

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Their notion was that the application of water to land was ruinous. Mr. Scott had mentioned that the manufactures of some towns rendered the sewage unfit for use. As a rule, he (Mr. Latham) believed that that was not correct. Even the sewage of Manchester, which was the colour of ink, and contained a large amount of matter from dye-works, was capable of being utilised. It must be borne in mind that a plant has a discriminating power in selecting its food, and will not take up any injurious matter.

Mr. BATLEY said that in cases where the sewage might contain a large quantity of mineral poisons, those poisons would be intercepted by upward filtration before they could reach the roots.

Mr. LATHAM said that upward irrigation and underground pipe system was a system which he did not at all approve of. It was one intended to get rid of and waste sewage rather than to utilise it. The great problem of the day was not how to waste sewage, but to utilise it. The evils resulting from the presence of mineral matters in sewage were imaginary.

The CHAIRMAN said he thought that it might clearly be seen from the discussion that the system of using town sewage for irrigation was good, and ought to be continued for the benefit of mankind. The pollution of rivers should be as soon as possible stopped. In his opinion, the outlets of the main sewers were much too near London. There was a scheme in existence for carrying the sewage on the north side much farther down than the present outlet, which he hoped would be carried out. He should recommend that the ventilation of the London sewers should be effected by means of ventilators, such as had been described by Mr. Rawlinson, for although the stench arising from the sewers might be innocuous to the system, it was not at all pleasant. The ventilation of the sewers at Woolwich, by means of the Dockyard shafts, might be very convenient and economical when the shafts were already built for other uses; but he believed the draught thus created affected but a very short length of the sewers.

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May 7th, 1866.

ZERAH COLBURN, PRESIDENT, IN THE CHAIR.

ON INCRUSTATION IN MARINE BOILERS.

BY P. JENSEN.

THE question of keeping marine boilers free from deposit or incrustations has for many years been one of the most prominent before the profession, in fact, ever since the first steamer entered sea-water, and it is still well worthy our closest attention. It presents itself to us principally in three distinct forms, namely, safety against explosions, economy of fuel, and durability of the boiler itself. Now, we all know that sea-water causes incrustation and corrosion, when boiled in a close vessel like a steam boiler. It is not, however, intended to enter into the question of internal corrosion of marine boilers, though closely connected with the subject before us, for fear of extending the length of this paper; but we may, in passing, note the fact that internal corrosion below the level of the water in a marine boiler does take place to some extent where the scale has been removed, but that otherwise this scale, so injurious when allowed to accumulate to any thickness, acts the part of a shield or protector to the plates of the boiler against the action of certain salts contained in sea-water, of which the muriate of magnesia is by far the most destructive, though, happily, small in quantity. And here the author may be allowed to call the attention of the meeting to an excellent paper "On the Wear and Tear of Boilers," read before the Society of Arts, April 26th, 1865, by Mr. F. A. Paget, who treats the subject of corrosion of boilers very fully. In the ordinary practice of sea-going steamers with common condensers, the feed-water is drawn from the hotwell of the condenser, and thence forced into the boiler at some point or points near the bottom, and at a temperature of about 110° Fahrenheit. The evaporation of steam leaves all, or sensibly all, saline or other extraneous matters contained in the water behind in the boiler, and unless some means were adopted against it we should, of course, soon get the boiler choked

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with incrustation or deposit. The means proposed or adopted for this purpose are many and varied, as will be seen in the sequel; but this much is certain, that any considerable thickness of scale allowed to accumulate renders the plates impervious to heat to a great extent, as this scale is a bad conductor. The heat generated in the furnace, and heating the plate next to it, cannot readily enough penetrate as far as the water, which, if in constant circulation, continually exposes fresh particles to the action of heat. The consequence is the overheating of the plates, and this to such an extent that holes may be burnt nearly through, leaving a sheet of iron the thickness of writing-paper. That explosions do and must occur by thus weakening the plates or by rents thus formed is an established fact, and has for years formed the subject of many investigations and different theories, among which that called the percussive, first started and since completed by Mr. Zerah Colburn, seems the most natural, and has now probably become more generally adopted than any other. But even only partial explosions caused by rents or collapse of internal parts of the boiler have proved dangerous by scalding those that happened to be near at the time. The conducting power of wrought iron decreases with the temperature, so that at 400° Fahrenheit it has little more than half that at 32° Fahrenheit; how it stands with still higher temperatures we do not know as yet. If from some reason or other, such as the coating of the plate with incrustation, which has sixteen times less conducting power than iron, the plate with its covering of crust should become heated to above 340° Fahrenheit, then the water would exist on its surface in a spheroidal state, and thus only slowly and by the forcible ejection of it by colder water enable the heat contained in the plate to diffuse itself into the water; thus the plate would get hotter and hotter, and at last burn or oxydise where next to the fire. It is thus that plates are burned nearly through on account of incrustation. Important as is the question of the safety of the marine boiler against explosions, it cannot be denied that the economy of fuel, as regards marine boilers, has at all times been a mere question of pounds, shillings, and pence, and commanded, it is believed, as much attention as the consideration of human lives: witness the numerous patents, amounting to about one hundred and fifty, that have been taken out in this country for the prevention of incrustations and consequent loss in evaporative duty in marine boilers. Now this is not an occasion for speaking about the patent laws, or entering into the desirability of maintaining, altering, or abolishing the same; but as one argument in favour of maintaining them struck the author while preparing this paper, which has a direct bearing on this and most other engineering questions, it would be worth while to hear

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what the opponents of the patent laws have to say against it. The question is simply this, how and where should we find such a complete record of the progress of engineering inventive and progressive talent but for the record of the Patent Office? In spite of all the nonsense that is patented, no doubt in sober earnest, still we find a vast amount of information in the specifications of patents. Would those that speak against patent laws like to do without the patent specifications? To return to the subject, it has been said above that the scale has sixteen times less conducting power than iron. In an inquiry on incrustation of marine boilers by a Frenchman, M. Cousté (Annales des Mines, 1854), a paper hardly noticed in this country till Mr. Robert Trefusis Mallet, in *Practical Mechanics' Journal*, September, 1862, gave an extract of it, the following is stated: That with marine boilers, starting quite clean inside, a loss of 8 or 10 per cent. of the evaporative duty of the fuel takes place after the first few days' work (a fact every marine engineer is aware of). At Bordeaux he found 15 per cent., and at Havre, after some days' constant work, he observed 40 per cent. In general practice, he says, it has been estimated that 40 per cent. of the heat of the fuel is lost by internal incrustation or deposit.* He gives the following analysis of the incrustations:

Stations.	Sulphate of Lime.	Carbonate of Magnesia.	Free Magnesia.	Iron and Aluminum.	Water.
Hamburg (deposit from the surface of boiler partly crystallised).....	85·20	2·25	5·95	...	6·5
Mediterranean, tubular boiler (amorphous) ...	84·94	2·34	7·66	·41	4·65
Mediterranean (amorphous deposit)	80·90	3·19	10·35	6·50	4·56

The water contained is believed to be mechanically present in the pores of the scale, and not chemically dissolved. Of course marine boilers are scaled as often as it can be done; but for long voyages it is often out of the question. Starting with 20 lb. pressure in the boiler, and clean fires, it is generally found that on the second or third day, in spite of greater exertions of the stokers and harder firing, only 19 lb. or less can be kept constantly, and this loss in efficiency goes on at an increasing rate. In eight days' constant steaming it has been found (in one instance) that, starting with 22 lb. pressure, the same was reduced to 15 lb. at the end of the voyage; this, it is supposed, without at all forcing the firing. Take another instance, at random, the *Persia* log,

* This is, however, overrating the case considerably.

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from the year 1858, September 30th to October 9th, inclusive: Total number of nautical miles travelled, 2886; total quantity of coals consumed, 1402 tons. But whereas the consumption of coals per hour per indicated horse power was 3·95 on 30th of September (it left New York on the 29th), it had increased to 4·314 on the 8th of October (*Artisan*, May 1860). These few items illustrate sufficiently the well-known fact that incrustation, even only as thick as paper, has a very great and perceptible influence tending to counteract the economy of fuel.

As to durability: marine boilers, with all care, on an average only last five years; but this is chiefly owing to internal and external corrosion, rendered more intense by the salts contained in sea-water, which, besides, promotes galvanic action in various ways. This must be understood to apply to boilers properly managed; that is to say, in such a way that only a very thin scale is allowed to be formed; for, as mentioned above, if thick scale is formed anywhere in places exposed to the heat of the furnace, or the escaping gases, this circumstance contributes directly to the burning away or oxidising of the plates. This fact, that marine boilers wear out so quickly, must, as far as can be seen at present, remain unaltered so long as salt water is employed, and in spite of repeated trials, and more or less success of surface-condensing in some instances, still we are far from the general introduction of surface-condensing, and considering the vast number of marine engines in existence worked with common injection condensers and salt water in the boilers, leaves the importance of the subject under consideration intact. It is now proposed to give a general explanation of the action of sea-water as it obtains in the marine boiler. The specific gravity of sea-water varies according to different localities; and calling that of pure distilled water 1000, the average specific gravity of sea-water, according to Faraday, is 1027. For sea-water of the specific gravity of 1027·2, such as he used in his experiments, one cubic foot weighs 64·1416 lb., or 1026·265 oz. avoirdupois, and contains of

	Ounces.
Chloride of sodium, or common salt	25·762
Muriate of magnesia	3·282
Sulphate of magnesia	2·212
Sulphate of lime	1·013
Total	32·269

besides small quantities of other salts, but too minute to be of any consequence.

Dr. Ure found the largest proportion of salt held in solution, in the open sea, to be 38 parts of 1000, and the smallest 32; the

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Red Sea, however, contains 43 parts in 1000; the Baltic contains 6·6; the Black Sea, 21; the Arctic Ocean, 28·5; the British Channel, 35·5; and the Mediterranean, 38.

The following Table shows the boiling point and specific gravity of water of different densities at a barometric height of 30 in. of mercury:

	Saltness.	Boiling point.	Specific gravity
Pure water	0	212°	1·000
Common salt water	$\frac{1}{32}$	213·2	1·029
	$\frac{2}{32}$	214·4	1·058
	$\frac{3}{32}$	215·5	1·087
	$\frac{4}{32}$	216·7	1·116
	$\frac{5}{32}$	217·9	1·145
	$\frac{6}{32}$	219·1	1·174
	$\frac{7}{32}$	220·3	1·203
	$\frac{8}{32}$	221·5	1·232
	$\frac{9}{32}$	222·7	1·261
	$\frac{10}{32}$	223·8	1·290
	$\frac{11}{32}$	225·0	1·319
	$\frac{12}{32}$	226·1	1·348

The deposit of salt begins at a density of $\frac{4}{32}$, and at $\frac{12}{32}$ we have arrived at the point of saturation, or the point at which water is incapable of dissolving any more. According to M. Cousté, an imperial gallon of water is capable of holding in solution at 60° Fahrenheit and at boiling-point, namely, in the open air, the following weights, nearly:

	At 60° Fahrenheit.	At boiling point.
Carbonate of lime	Merely traces	merely traces
Silica	70 grains	"
Sulphate of lime	170 "	"
Carbonate of magnesia	3·25 ounces	"
Sulphate of potassium	10 "	40 ounces
Chloride of sodium	32 "	30 "
Chloride of magnesium	266 "	580 "
Nitrate of lime	500 "	? "
Chloride of lime	540 "	unlimited

The order of deposition in the boiler, as the water becomes concentrated, is:

1st, carbonate of lime; 2nd, sulphate of lime; 3rd, the salts of iron, or oxides, and some of those of magnesia; 4th, the silica or alumina, usually with more or less of organic matter; and 5th, chloride of sodium, or common salt. Now it is well known that sulphate of lime is the worst of all the salts in a marine boiler. We have seen that $\frac{12}{32}$, or 37 in 100, is the point of saturation for common salt; but in the case of sea-water, which contains other salts besides, 36 parts in 100 saturate at 226°, and 30 in a 100 at 228°. Now, taking 20 lb. pressure, which is the most prevailing now, this, with a saturation of $\frac{3}{32}$ to a rise of 1·2° per

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$\frac{1}{32}$, according to Professor Rankine, corresponds to a temperature of, say, 262·9° Fahrenheit. How much salt can be held in solution at that temperature is not known to the author; but it is well known that the quantity decreases with increased temperature, and this is the reason of our not having yet arrived much beyond 20 lb. pressure in marine boilers working with salt water. In marine boilers we have chiefly to do with sulphate of lime, the proportion of the same so largely preponderating in the incrustation on analysis. As to carbonate of lime, this enemy to boilers is fortunately not a constituent of salt water except in the Mediterranean, which contains a trace of it (·001 in 100 parts).

Sulphate of lime forms deposits at all temperatures and all densities. Salt, on the contrary, forms deposits, as we have seen in the foregoing, not to any extent except when in the quantity of $\frac{3}{32}$ or $\frac{4}{32}$, the quantity of the same required for saturation decreasing with increased temperature, and the amount of deposit that will take place long before the point of saturation having been arrived at increasing with increased temperature or pressure. Sulphate of lime will deposit at any temperature; but it so happens that increase of temperature also increases the amount of deposit of this salt, for, according to M. Cousté, the solubility of sulphate of lime at different temperatures is as follows. The Table indicates the solubility for different temperatures, as well as degrees of concentration at which the saturation of sulphate of lime takes place:

Degrees of areometer corresponding to the saturation.	Temperature.		Total pressure in atmospheres.	Solubility, or proportion of sulphate of lime in 100 parts of water at saturation.
	Fahr.	Cels.		
12½	217·4	103·00	1	·500
12	218·84	103·80	1	·477
11	221·27	105·15	1	·432
10	227·48	108·60	1¼	·395
9	231·8	111·00	1¼	·355
8	235·76	113·20	1¼	·310
7	240·44	115·80	1½	·277
6	245·3	118·50	1½	·226
5	250	121·20	1½	·183
4	255·2	124·00	2	·140
3	261·68	127·60	2	·097
2	266	130·00	2½	·060
1	271·94	133·30	2½	·023

Now this Table, and that of the amount of salt which can be held

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in solution at high pressures, say 20 lb., a Table the author believes not to be found anywhere, would give us, as near as possible, the quantity of water that ought to be blown out of a boiler to prevent, 1st, accumulation of chloride of sodium, and, 2nd, the deposition of sulphate of lime in any quantity injurious to the boiler in any high degree. True, there is one way of getting over the difficulty, namely, working with a lower pressure, but this is out of the question for several reasons, and we must hence use experience and experiments as our guide. From the foregoing, it will be clear that every pressure requires a different treatment and a different amount of water to be blown off. If you blow off more than is necessary to prevent accumulation of salt in the boiler, you have to pump a greater quantity of feed-water in, and consequently a greater amount of sulphate of lime in solution, which will be deposited as a hard tenacious scale. On the other hand, if you blow off too little, you will certainly get less sulphate of lime, but the accumulation of common salt will ultimately choke the passages in the boiler. This maxim, though true in theory, is modified in practice, because of disturbing elements, namely, the more or less rapid circulation of the water. To strike the just balance, it is, as before said, necessary to be guided by experience. It seems that ignorance has prevailed in high quarters till very late years, because of want of data. Thus we find that Mr. James Napier read a paper in 1859 before the Institution of Engineers of Scotland, in which he recommended the use of a much larger regenerator (a sort of tubular feed-water heater, the heat of the brine blown off being made use of for that purpose), and blowing off to a greater extent than generally used. He tried the experiment himself, and gave the results in a paper, read February 17, 1854, before the same institution. For the screw steamer *Lancefield*, trading regularly between Glasgow and the Hebrides, he made a regenerator of ten times the usual surface, and blew off to such an extent as to keep the density of the water in the boiler at very nearly the same point as the water in the sea. After four weeks' running, the boiler was examined, and instead of its being clean and free from scale, he found, to his surprise, it was coated with a much thicker scale than under usual circumstances, but soft, like newly made mortar, but it dried and hardened before he could get it all out, and it was then nearly as difficult to scrape as the ordinary hard scale. On one voyage, when he was present himself, he gave the boiler as much feed as the pump would do, and he observed then that the water in the gauge glass was muddy. He continued the experiment for six months, but with lesser quantities of feed, and blew off till the tubes of the regenerator gave way, and then he discontinued. He saw then M.

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Cousté's paper and the table contained in the same, which shows that at two atmospheres pressure sea-water becomes saturated with sulphate of lime even at the ordinary density, and as he loaded to 40 lb., and generally worked at about 30 lb., he saw at once the explanation of the phenomenon. Although he blew off constantly from the surface by a conical tube, only some of the deposit of precipitate matter could be got rid of. This tallies exactly with the experience of some others. Some steamers in the American navy work with about, or nearly, 30 lb. pressure and salt water, but it is believed not with our ordinary tubular boiler, but with long cylindrical boilers having large round tubes and very ample water-ways. In the discussion following, Mr. Elder said he had worked marine boilers with 30 to 35 lb. and salt water. One naturally expected to find most deposit in that section of the boiler which contained most salt and lime, he said, but in a boiler divided into eighteen parts (supposed to refer to his spiral flue high-pressure boiler), he found that though in the last section there was 2½ times more salt in the water than in that of the first section, yet the deposit of lime was about equal in all parts. He concluded that the amount of deposit of lime depended on temperature, and not quantity of lime in it. The Americans, he said, ran with 40 lb. pressure, and did not appear to suffer from deposit, but they cleaned the boiler whenever they came into port. He found the deposit to be greatest where there was no current. He had observed boilers running with 45 lb. for three or four months, and there was not much more deposit than when working with 25 lb. He believed that there was a greater tendency for the lime to separate and deposit, but it did not necessarily settle down on the heating surface of the boiler.

The *Mechanics' Magazine*, in an article on Incrustation in Marine Boilers, February 24th, 1860, mentions Mr. James R. Napier's paper, and assumes, for want of better data, 28 parts of sulphate of lime to 1000 of solution as the limit of saturation in boilers working at a pressure not exceeding 20 lb., and finds that with this assumption half the water must be discharged to keep the boiler clean, and this is affirmed by the practice of the British and North American Mail Company and others. Mr. Thomas Rowan found that when he had evaporated

$\frac{3}{10}$	of the water	a trace of sulphate of lime deposited
$\frac{4}{10}$	"	" "
$\frac{5}{10}$	"	sulphate of lime deposited in larger quantities;
$\frac{6}{10}$	"	" " decided quantities.
$\frac{8}{10}$	"	" very large quantities, also magnesia;

and salt began to form. It is probable, therefore, that half or

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more of the water would have to be blown off in order to prevent formation of crust. This means, that the density of the water should be kept at $\frac{2}{32}$, for as sea-water contains $\frac{1}{32}$ in its pure state, it is evident that half the water must be blown off to keep it at double its natural density. It may here be remarked that a density of $\frac{3}{32}$ is very generally kept in marine boilers, using about 20 lb. pressure of steam; and if this be constantly and carefully attended to, no considerable or deleterious thickness of scale accumulates, at least in places where the circulation is good.

We come now to a brief survey of the various means proposed, or adopted, for preventing incrustation. They consist in

1. Surface condensers.
2. Heating the feed-water to such a temperature before entering the boiler, so as to oblige the sulphate of lime and other salts to accumulate in the heater only.
3. Introducing various substances into the feed-water before entering the boiler, the feed-water at the same time being subjected to heat so as to throw down the salts without allowing the same to enter the boiler.
4. Introducing various substances into the boiler so as to neutralise the effect of the salts; and
5. Blowing off in the usual or various other ways.

1. Surface condensers. This seems at once to do away with the nuisance; the economy anticipated has not, however, been quite realised in practice. It has been found necessary to inject a little salt water along with the distilled water from the condenser, and the duration of the boiler has been found, in many cases, to be even shorter than with salt water only, the reasons for which it is not thought necessary to enter into here.

2. Heating the feed-water, before entering the boiler, to such a degree that the salts are supposed to be thrown down in the heater instead of the boiler. This looks very feasible, but after all it amounts to shifting an evil from one place to another; let the heater be choked with salt and incrustation, and the engineer in charge has his hands as full as ever. To be admissible on board ship it must be compact, and at the same time accessible for thorough scaling, two conditions not very easily reconciled. The most practical shape is that of a casing with a number of dishes or shells piled on the top of each other in the same, which can be taken out and replaced by clean ones in a short space of time. This plan was patented by Mr. Spencer in 1863, No. 896; and in 1864, No. 86, by M. L. E. E. Martin, a French civil engineer. It is possible that this idea, by no means novel, possesses practical value, and at some future time may prove successful.

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3. The plan of medicating the feed-water in a heater before it is admitted to the boiler, feasible and correct in principle as it appears, resolves itself, however, in a commercial question, and is contingent upon the price, and bulk, and other qualities of the substances proposed to be used for neutralising the salts contained in the feed-water. Many substances have been proposed for this purpose, some evidently not of a harmless character, as regards the iron plates of the heater, some evidently so expensive as to be out of the question, and only one or two of a really feasible character. This latter class will be treated under the next head.

4. The plan of admitting foreign substances into the boiler to neutralise the salts, or some of them, contained in the sea-water, has found favour with a great many inventors; suffice it to say, that nothing has appeared more likely, in the eyes of practical and scientific gentlemen, than soda. Mr. J. R. Napier has gone into an estimate of the commercial advantage of using soda ash for incrustations. He assumes the boiler to work at 270°, or about 26 lb. per square inch, and evaporating at that temperature $7\frac{1}{2}$ lb. of water from 100° per lb. of coal. The following is his Table:

	Mechanical method.	Chemical method.
Sea-water supplied to boiler at 100°	15 lb.	8·33
Water discharged at 270°.....	7·5 lb.	·83
Water evaporated.....	7·5 lb.	7·5
Total heat evaporating from 100° at 270° = 1092 × $\frac{A^1}{10}$ (T_1 32 − T_2 32) = 1095.....	8215·5°	8215·5°
Heat discharged.....	1275°	142°
Fuel consumed in evaporation.....	1 lb.	1 lb.
Fuel consumed in preventing crust	·155 lb. coal	·0172 lb. coal × ·0085 lb. soda ash
Total fuel.....	1·155 lb. coal	1·017 lb. coal × ·0085 lb. soda ash

Thus it seems, he says, that it requires only 172 lb. of coal + 85 lb. of soda ash containing 50° of soda to be as efficient in preventing crust as 1550 lb. of coal alone, which evaporates $7\frac{1}{2}$ lb. of water from 100° at 270°. And these methods are equally expensive when soda ash is 16·2 times dearer than coal. This ratio varies with the efficiency of the fuel and the temperature of the evaporation. In this instance the loss by blowing off amounts to 14 per cent. Now, there is no doubt that soda is a very good remedy against incrustations, and it has been repeatedly recommended by eminent chemists. Unfortunately, even this remedy, so simple and efficacious as it has proved, has its drawback, and

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that of a very serious nature. In a German scientific periodical, "Dingler's Journal," vol. 130, page 153, A.D. 1853, we find it mentioned that Professor R. Fresenius had recommended the use of a certain quantity of soda as a certain and cheap means for preventing incrustations where water is used that contains sulphate of lime (or plaster of paris). He had used it some months, and with very good results. The factory boiler in question, that formerly used to be scaled at proportionately short intervals, now remained perfectly clean, and even patches of old incrustation, too hard for removal, had disappeared.

But repeated trials and careful examinations had shown that a continued use of soda attacked the boiler-plates very much. Dr. Zimmerman thought that all commercial soda contained more or less cyan, and that this was the reason of the corrosion of the plate; Dr. Rudolph Böttger, who mentions this fact in his "Polytechnisches Notizblatt," of 1853, No. 20, says that he has made several experiments himself, according to which all commercial soda, even from the most respectable firms, contains cyannatrium, and in consequence of this discovery he warns others against using it in boilers for the purpose of preventing incrustations. It is important to bear this fact in mind at a time when we find the chief inspector of the Manchester Boiler Association recommending the use of soda in steam boilers. Besides, it must be remembered that such foreign bodies introduced into the boiler produce priming with all its evils.

5. Blowing off. The original practice at sea was, it is believed, to blow off from the bottom only, which was not found efficacious. Subsequently, additional blowing off from the surface was resorted to, and this first at stated intervals and afterwards continuously. Thus we find Henry Maudslay and Joshua Field already in 1824 taking out a patent (A.D. 1824, No. 5021) for withdrawing a fixed quantity of brine by meters of any kind; they preferred a pump with a loaded discharge-valve drawing from the lowest part of the boiler. They also in this patent mention a tubular regenerator for heating the feed-water by means of the heat of the brine drawn off. These brine pumps were at one time used to some extent, but have now been superseded by the surface blow-off system, because it was found that the pumps and the regenerator got choked with salt, and thus became inefficient. Blowing off from the bottom has now become almost superseded by surface blowing off, because the latter plan has been found the more efficient of the two. The impurities contained in the sea-water being, by the application of the heat of the furnace, brought out from the state of chemical solution into that of mechanical mixture in minute particles, floating about in the hot water and steam, are, by the circulation

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of the steam and water, floated to the surface in or along with the globules of steam rising to the surface and there held in suspension in the bath of steam and water till accumulating to such an extent as to subside to the bottom; or, in their downward course adhering to the surfaces coming in their way. It is hence obvious enough why it has been found advantageous to catch these impurities before they can do any harm and blow them off.

Intimately connected with the question of blowing off is that of sediment-collectors. Various sorts have been proposed for this purpose; but it is not proposed to enter into this subject, for the reason that, applicable as they might be for many other sorts of boilers, they are not, in the author's opinion, as regards marine tubular boilers as now universally adopted, except in the shape of one or two common scum-pans; because any comprehensive system of pipes, pans, and vessels of any sort in the water-room above the tubes would impede the free circulation of the ascending and descending currents, and thus probably do more harm than good. The author is, however, open to correction, in these remarks, by practical men having actually tried such appliances. And this leads to the consideration of, probably, the most important element in the prevention of incrustation in marine boilers, namely, the influence that the construction of the boiler itself has upon the subject.

If, as has been shown in the foregoing remarks, the sulphate of lime becomes all but insoluble in sea-water at a pressure of 20 lb. per square inch above the atmosphere, such as is now commonly used in marine boilers, and if it is a fact, nevertheless, that incrustation can be prevented in some boilers by means of proper and assiduous care, while no amount of care will prevent it in others, then we must arrive at the conclusion that the construction of the boiler, next to proper and convenient means of constantly observing the state of the water and careful attention to it, forms the most important point in the inquiry. You may build marine boilers of very much the same general internal and external appearance to a superficial observer, and still one is a good and the other is a bad boiler to keep clean and to scale. It is obvious that it is only by the rapid and free circulation of the water and steam that we are enabled to work with salt water at all. It is further probable that but for the circumstance that the circulation becomes more rapid as you increase the working pressure, and consequently the temperature, that higher pressures than 20 lb., going even as high as 40 lb., have been found practical with salt water. The chief principle to be aimed at seems this: wherever the greatest heat is communicated to the plates, there also ought to be the greatest facility given for a rapid

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circulation; and, secondly, make the boiler accessible in all its internal parts, and especially in those most vital, namely, those in which scale when formed is most injurious and dangerous, which are those exposed to the greatest heat. The scanty room generally allotted to marine boilers makes it a difficult task for the designer to meet the above requirements without at the same time losing sight of other important considerations, such as economy and strength. The common multitubular marine boiler may be so designed, and this does not happen very often, that it gives little trouble to the engineer in charge to keep clean and scale it: the tubes must not be too close upon each other, and not too many rows in the vertical line; ample room must be left for a man to get in to clean the furnace crown, the back tubeplate, and the spaces between the tubes. The plan of inclining the back tubeplate somewhat so as to allow the steam to escape more freely from the same has found favour with many engineers, and has also collateral advantages. Of late years a multitubular boiler of another description, the vertical water-tube boiler, by Mr. Martin, a chief engineer of the United States Navy, has become extensively adopted in the United States Navy, and possesses, no doubt, advantages as regards scaling the tubes, the water being in them, and heated products of combustion passing outside and amongst them; this circumstance renders them more easily scaled inside with circular scrapers than is practical with the tubes in our common marine boilers, that want scaling outside and never can be effectually scaled by mere mechanical means. The "Field" boiler, now well known amongst engineers, and because of the very rapid circulation in the tubes possessing the important advantage of keeping the tubes themselves and also the tubeplate in which they are inserted free from scale, ought to do well for marine purposes, one should think, although, of course, practice will answer that question. In American men-of-war, where they seem to be able to afford more boiler space than in the British Navy, is often used a long circular return-tube boiler, the tubes being of large diameter (say 1 ft. or more), with very ample water spaces around and between them. They are, on account of their shape, capable of working with 30 lb. to 40 lb. per square inch, almost without staying, and also to use salt water at that pressure. Many other boilers proposed or adopted for marine purposes might be mentioned, but it would be to travel beyond the subject to go into details of this question. To illustrate the importance that has at all times attached to this subject, it will be well to enumerate the more prominent patents that have been taken out in this country for preventing incrustation in boilers.

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Messrs. Maudslay and J. Field, 1824, No. 5021. This has been mentioned before.

Mr. W. A. Johnson, 1838, No. 7714. He proposes to put pieces of broken glass into the boiler, or broken porcelain, pottery, scraps of iron, shot, steel, or other hard substances, which he thinks, by the circulation of the water, will be scoured against the sides of the boiler, and keep it clean! The circulation must be very strong indeed.

Mr. J. I. Delfossé, 1848, No. 11,347. He adds a compound consisting of dry tannic or gallic extract, hydrate of soda (soda without carbonic acid), muriate of soda, and subcarbonate of potash. The proportions vary according to analysis. For locomotives and marine engines he adds this compound every two days or more.

Mr. J. I. Beale, 1848, No. 12,185. He adds a compound consisting of human urine with a little caustic potass, soda, or lime. Two ounces of this per cubic foot of water contained in the boiler. Marine boilers, he says, must be blown off in the usual way.

Mr. J. Horsley, 1849, No. 12,592. He proposes to purify the sea-water before going into the boiler, by treating it with oxalate of potassa and ammonio-phosphate of soda; for water as in the British Channel, he uses 2 drachms of oxalate of potassa to 2 oz. of ammonio-phosphate of soda for every gallon of water. The precipitate forms a splendid manure. But it requires a very nice analysis so as not to render the water injurious by an overdose.

Mr. B. Babington, 1850, No. 13,322. He connects some more oxydable substance than the boiler-plates to the same in this way: he solders to the sides of the boilers in the water space sheets of zinc by one edge, leaving the other edge free, and the two sides just immersed. This zinc corrodes, and, by the voltaic action between the iron, the sea-water, and the zinc he thinks he prevents the incrustation.

Mr. J. Ashworth, 1851, No. 13,647. To 33 gallons of coal-tar he adds 21 gallons of linseed-water (prepared by boiling in water 14 lb. of linseed, and straining seed away) and 5 lb. of plumbago, or common black-lead, pulverised, and 8 lb. of Castile soap. He uses 1 gallon of this per 30 horse power twice a week. He finds this prevents incrustation, so that scale only forms in thin, brittle, and porous quantities, easily swept away.

Mr. A. V. Newton, 1852, No. 14,062. He uses a compound called Sibbald's metalline compound, composed of tallow, or suet, 1 lb., graphite, or black-lead, 1 lb., charcoal, fine dust, $\frac{1}{8}$ of a pound. He first melts the fat, and then mixes. He then adds a gill of oil or gas-tar. When using, he warms it first, and then

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paints the whole inside of the boiler, which must also be slightly warmed. Applied to a foul boiler, the incrustation becomes softened, and can be swept off. He says it prevents the formation of new scale, and helps even to the evaporating efficiency. It should be applied once a fortnight.

Mr. F. Dam, 1852, No. 14,262. He proposed to use hydrate of potash, or soda, which he dissolves in water, forming a saturated solution. He introduces it by a pipe having two cocks (like a grease-cock on a cylinder), or by means of a pump. Or he applies it to water before going into the boiler. To ascertain the proper amount, he takes a measured quantity and adds some drops of solution as long as it makes a milky cloud. The water is then filtered, and some more solution put in; and if no more precipitation takes place, the former quantity is the right one.

Mr. W. Dantec, 1852, No. 589. This inventor passes all feed-water through a filter. The latter consists of powdered charcoal between surfaces of hair-cloth, by preference; first he precipitates the lime by caustic baryta, or soluble salts of baryta, including sulphuret of barium, or else oxalate of ammonia. The filtering apparatus is an iron tank with perforated frames, one inside the other; the spaces are filled with powdered charcoal. For marine or condensing engines he connects the hot well and the filter by means of a pipe for supply of water, and by a small pump he supplies the requisite quantity of solution of baryta to the water as it passes from the hot well. The feed-pump draws the filtered water off, and pumps it into the boiler. To say nothing else against this plan, the filter would have to be of enormous dimension.

Mr. A. V. Newton, 1852, No. 1041. He patents a self-acting apparatus for blowing off, regulated by the density of the sea-water itself. A hydrometer floating in the bolier-water combined with, and to govern, the motions of an independent mechanism, actuated, by a motive force, to operate a valve or valves which govern discharge of liquid when its density or gravity becomes too great, or *vice versâ*, or the supply of fresh liquid, or *vice versâ*. The hydrometer, by a rather complicated arrangement, acts as a float, the rise and fall of which regulates the opening of the blow-off cock. How this apparatus would fare in a gale of wind, with the vessel pitching and rolling, does not seem to have entered the inventor's mind.

Messrs. Dangerfield and B. Dangerfield, jun., 1853, No. 2596. They employ a concave or cup-like vessel in the interior of the boiler at water-line; scum collects in this vessel, and is taken off by a pipe at the bottom of same, and thence blown off. This is a very old and well-known plan.

Mr. R. Hoyle, 1854, No. 2078. He places a perforated

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vessel containing bark or other suitable matter in a cistern partly filled with water, and heated by the waste steam or otherwise. The solution of bark or other matter thus formed is forced into the boiler.

Mr. G. J. Bousfield, 1854, No. 2442. The water before entering boiler is subjected to heat by waste steam in a long vessel with mudholes. The water flows out at one end into a perforated cylinder filled with sawdust, birch twigs, or thorn of broom mixed with wheat bran. Also a lower cylinder of wire cloth or perforated plate containing horse-dung. These cylinders or sieves are within a jacket, into which the steam flows, and from thence into the atmosphere. The water thus heated and filtered flows into a supply vessel with a float to cut off supply of feed-water to the apparatus, and with cocks and valves in such a manner that when the further incoming of the water is stopped in respect to supply vessel, and steam admitted from boiler into supply vessel to equalise the pressure, the water will flow into the boiler.

Mr. J. H. Johnson, 1854, No. 2466. Introduction of raw or tanned scraps of hide into the steam generator. For convenience' sake a lot is boiled together into a soft mass, and put into the boiler in the shape of a ball, or else scraps of leather enclosed in a bag. It is preferred to use it as a powder.

Mr. J. A. Manning, 1855, No. 882. Introduces air-pipes to produce currents, and thus prevents incrustation.

Mr. E. Topham, 1855, No. 1830. Applies inside near the bottom apparatus, for agitating and drawing off occasionally, a shallow scraper with one or more rods attached for working from outside. At back of boiler, at bottom, is an opening with a long blow-off pipe perforated at bottom; by moving the scraper to and fro the sediment is loosened and blown out. The holes in pipe collectively must be less than the area through cock; this is mainly important. For sediment too light to be precipitated he has fans that throw the scum into gutters near surface and alongside of boiler, in which lies the perforated pipe.

Mr. C. Walker, 1856, No. 340. Uses a scum-collector; a pipe with slots or holes on each side above centre-line is supported at each end with its axis at the water-level. It has a lever with a float at the end, so that as ebullition goes on the collector oscillates and thus exposes a number of holes for blow off. The bottom of the tube has no holes, and from that scum is taken off by a pipe dipping into it.

R. B. Lindsay, 1856, No. 879. Applies highly heated steam or air to cause the incrustation to crack, the boiler being cold at the commencement of the process. This method has been tried

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with great success in the royal navy, and seems to offer great advantages wherever it can be applied.

A. C., L. C., and J. L. Casartelli, 1856, No. 2623. A salinometer consisting of two tubes, the ends of which are supported in two cocks; one cock is marked "blow," and the opposite one "limit;" each tube contains a bead or float adjusted to certain gravities, that in tube "blow" being lightest. When density of water reaches gravity of float in tube "blow," the same will rise in tube and indicate that more feed should be admitted; but the float in tube "limit" will not rise till density exceeds that of the other to a certain extent. When float in tube "limit" rises water should be fed in to prevent too great density. This instrument may also be used as a water-gauge. The above plan is not unlike Seaward's salinometer patented many years ago.

Mr. H. Hobbs and E. Easton, 1857, No. 1316. Solution, or paste, composed of arsenic and soda, or other alkali; when as a liquid, it is to be pumped in, and when as a paste, laid on with a brush.

Mr. Paul Ingwersen, 1857, No. 1415. Burgundy pitch, alone or mixed with $\frac{1}{3}$ of charcoal or pure soot, to be applied in boiler whilst heated.

Mr. W. E. Newton, 1857, No. 1949. The black gum catechu is employed. To 100 H.P. boiler add about $\frac{1}{2}$ lb., and allow to remain till water becomes of the colour of pale brandy; small pieces are added daily to keep it at that colour. No incrustation will then ensue. This, he says, does not choke up.

M. Guillaume Défis, 1857, No. 1976. For a boiler of 200 H.P., suitable for a month:

	lb.		lb.
Crystallised salt of soda	60	Tanning	60
Potass	40	Tallow	20
Plumbago	20	Flower of sulphur . .	4
Ashes of vine branches .	60	In addition to these, volatile ammonia may be added to remove incrustations.	
„ pine-wood . .	20		
„ walnut . . .	60		
Soot	10		
Linseed cakes . . .	20		

The above are mixed with the sea-water in a paste.

Mr. J. Hall, 1857, No. 2015. Sediment-collector. A series of plates, one inside the other, in which are formed apertures or spaces for the passage of the water and sediment into interior of vessel; the apertures are so arranged that the aperture of one plate may alternate with an obstructing piece of metal in the next plate, and thus overcome the agitation of water passing from the boiler before it reaches the interior of the vessel.

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Mr. J. Sheddon and J. Marsland, 1857, No. 2385. Washing rock soda, or carbonate of soda, or soda ash, or bicarbonate of soda, or compositions of any or either of them, either as a powder or liquid.

Messrs. A. and J. Martin, 1857, No. 2945. Crystallised carbonate of soda, wood ashes, and plumbago mixed and placed in a separate vessel in connexion with the boiler. For a boiler already incrustated they propose to add besides hydrochlorate of ammonia.

M. E. Coulon, 1858, No. 607. Plumbate and plumbites of potash and soda, and the insoluble salts of lead and chloride of zinc, added to a feed-tank or to the boiler itself. He prefers to add a quantity of sand, clay, red ochre, and muriatic acid.

M. H. A. de Saegher, 1858, No. 888. Dried pitch melted with stearine, or common grease, by application of heat; then add wood ashes and ground charcoal, and mix them well by stirring; then cool it and make it up into balls ready for use.

Mr. J. Braidwood, 1858, No. 915. A vessel connected near the water-level and the bottom of the boiler, the bottom of the vessel being lower than the bottom of the boiler. A current is produced, and the water absorbs matter in vessel and precipitates, and is drawn off by a cock from the very bottom of the vessel.

T. Holt and J. Brown, 1859, No. 1042. This patentee uses a feed-water heater, which he also uses as a receptacle of mixture for purifying the water; he uses spent tanners' bark, bark knots, &c.

M. C. F. Vasserot. Extract of chesnut, or any other substance containing gallic and tannic acids.

Brooman, 1859, No. 1824. Leather, or waste leather.

J. and R. Blinkhorn, 1859, No. 1833. Animal fat or grease, fullers'-earth, soda mixed with neatsfoot or colza oil, night-soil, and Nixey's washing powder; 1 lb. per 12 hours for an 8 HP. boiler.

M. L. Sorbas, 1859, No. 2884. Any tannate of gelatine, as well as leather.

M. L. M. Boulard, 1860, No. 938. A case or bag of perforated sheet metal, or wire gauze, or non-metallic gauze, corresponding to the inside shape of the boiler in which it is enclosed, forming a lining, kept at a slight distance from the side by means of brackets. The meshes are finer at the bottom than at the top. The lining may be made in sections. It has been ascertained, he says, that this prevents incrustations, and loosens those already formed.

Messrs. W. Allen and W. Allen, 1860, No. 1696. Ammo-

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niacal liquid obtained from coal or gas tar. For a new boiler, he paints it inside with several coats of gas tar.

Mr. C. J. Dinnery, 1860, No. 2988. Sediment-collector, consisting of a horizontal tube the length of the boiler, or nearly so, with one end communicating with the boiler by a vertical tube entering at or near water-level, the other end communicating with bottom of boiler, near the fireplace, by a horizontal pipe. Precipitation by simple gravitation. He says salt does not crystallise till the water is saturated with it, while the sulphate of lime crystallises at 334° Fah.; it is hence easy to separate sulphate of lime first by passing it through a worm heated to 150°, or you may have an apparatus for separating carbonate magnesial salts, a second for sulphate of lime, and the others for the vaporisation and extraction of the salt.

Mr. R. Armstrong, 1861, No. 1472. His patent consists of a boiler with a vertical circular firebox, with oval cross tubes, whose longest axes are horizontal in the centre, and vertical at the ends. He also has a plan for a feed-water heater, consisting of a cast-iron cistern, serving as foundation for boiler to stand on, and the heat radiating from the furnace heats the feed-water. This case is divided into two unequal parts by a partition across reaching to within ½ in. of cover or lid, which is to have a thick projecting convexity to dip at least 1 in. below surface of water when the larger part is fully charged with feed-water. The water expanding at the surface gradually passes over to top of partition to smaller part; the sediment settles in the larger part. He lines or lags inside of shell with wooden staves, to prevent incrustation.

Mr. P. Taylor, 1861, No. 2171. He uses pipes with long slots at the surface of boiler, or at the bottom, or both, extending the whole or greater part of the length, communicating with a discharge valve, that can be opened quickly by studs working in a spiral slot, causing a rush which he thinks will prevent sediment.

Mr. E. H. Hughes, 25 parts by weight of alum, 25 parts of salts of soda at 32°, 2 parts of red ochre, 3½ parts of sulphuric acid, 15 parts of brown fecula of potatoes, and 35 parts of distilled water; these are mixed and boiled in a certain way.

Mr. A. V. Newton, 1861, No. 2961. Tobacco as a decoction, or else in a bag.

Mr. R. Needham, 1861, No. 3235. A longitudinal pipe at the bottom of boiler connected to a cock or valve outside. The pipe has at the bottom an aperture for entrance of mud and sediment, and at top a number of vertical pipes, each with ventilator-shaped funnel at top of water-line, with mouth turn-

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ing towards front of boiler, the flow of water being from the front to the back.

Mr. Grimaldi, 1861, No. 3207. A rotary boiler, which, at one time, caused a very great sensation.

Mr. J. H. Johnson, 1862, No. 196. A fluid composed of 8 parts by weight of potash of commerce, or carbonate of potash, and from 2 to 8 parts of molasses, added to 100 parts of snail or slug liquor. Also apparatus for injecting the same. He has the feed distributed so that no very unequal temperature exists anywhere.

Mr. J. Webster, 1862, No. 1903. Depositing earth and saline matter by electricity on another surface than the heating surface. He introduces a sheet of copper and a sheet of zinc, and insulates them, as far as metallic contact goes, from the plates of the boiler. It will then be found that all earthy and saline matter will be deposited on the said copper plates. In tubular boilers he uses tubes of copper and zinc in contact, which can be readily removed.

A. Delme, 1862, No. 2257. A composition made entirely of bark of oak and pine, leaves of ammac-tree, ground and as a powder: a decoction of this condensed in density of about 10° Beaume, and to it added a quantity of cream of tartar and spirit of turpentine. Three pints are enough for every 1000 pints in boiler for about ten days.

Mr. J. Willson, 1862, No. 2583. Ground malt and woody fibres; a larger proportion for marine boilers.

Mr. J. H. Johnson, 1863, No. 2808. Snail or slug liquor 100 parts by weight; carbonate of potash 8 parts; molasses or treacle 2 parts; leaves of aloe 5 parts; animal marrow 2 parts; extract of tar at 12° Beaume 1 part; boiled together for 2 hours, and then 30 strained off, when liquor will be ready.

Mr. G. Spencer, 1863, No. 896. On some convenient part of boiler in connexion with the steam space, a close vessel furnished with a lot of diaphragms or dishes placed one over the other; through the centre or sides of each vessel he brings the feed-water pipe, so that it discharges into the top dish, from which it flows down from one to another through holes or spaces, with raised edges not quite so deep as raised edges round edge of dish. The whole interior is in contact with steam from boiler. In addition, he coats the inside of the vessel and dishes, and the inside of the boiler, with a suitable substance, such as Green's oxide paint, to prevent adhesion of deposited salts to the metal.

Messrs. W. L. Winans and J. Winans, 1863, No. 1582. In vertical tubular boilers of á peculiar construction is left a space in the midst of the tubes large enough for a man to go down and clean the tubes and the tubeplates. By having a solid body

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of water in this place, they also think the tubes will keep clean.

Mr. J. Burrell, 1864, No. 698. A salinometer, consisting of a covered tank divided into two unequal compartments, both connected to water in the boiler. The small one contains distilled water, and the large one brine, continually supplied from boiler by constant circulation. In each is a float, and each float connected to one end of a double-armed lever. The floats are weighted, so that the float in the distilled water rises, if water gets too dense, and *vice versâ*. The rocking-weight shaft of lever has another lever, which actuates the scum blow-off cock; when the float in the distilled water rises, the cock opens. There is also another float which actuates the feed-cocks. If a column of sea-water and a column of distilled water are placed side by side, the distilled water will rise ¼ higher than the level of the brine. When the density of the brine increases, the float will rise in distilled water and open the scum cock. There is a plate of glass in front of each to observe the state of the water.

Mr. A. V. Newton, communication from G. T. Parry, Philadelphia. To destroy or prevent incrustation he uses an electrical arrangement tending to neutralise the action which induces this deposit, it having been found by experiment that positive electricity expels or throws off, while negative collects, small particles, hence when, by ebullition or otherwise, positive electricity is liberated or collects in boiler, its action is to throw down particles in the form of crystals or scales. He says he has tried it often, and has found it to answer.

After this brief notice of the more prominent patents, it is intended, in conclusion, to mention some of the well-known constructions of salinometers; for if it be true, as it seems to be the prevailing opinion among marine engineers, and as it has been shown in the foregoing, that, after all, we must depend more upon blowing off than anything else to prevent incrustation in marine boilers, then the salinometer deserves more than passing notice. One of the first, in order of time, is that invented twenty-six years ago by the late eminent engineer, Mr. Samuel Seaward: illustrated by Figs. 1 and 2, from a drawing kindly furnished by his successors, Messrs. Jackson and Watkins. The instrument consisted in a strong glass tube A, about ¾ in. bore and 14 in. long, fixed at each end in a brass frame, to which are attached four cocks, one at each end and two at the side; by the two latter cocks the instrument is attached to the front of the boiler at such a height that the water in the boiler may fill the glass tube. On opening the two cocks attached to the boiler, the water will rise from the bottom of the same by a pipe from the lower cock and fill the glass; on closing these cocks and

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opening the upper one, two balls, BB′, are dropped into the tube, the first ball being adjusted to one degree heavier than the water is intended to be maintained at in the boiler, the second ball one degree lighter, then close the upper cock, leaving the communication with the boiler open. Now, if the density of the water should increase beyond the standard adopted, the lower ball would rise; and if it should decrease, the upper ball would sink. This is a very ingenious but rather delicate instrument, the use of which has now for many years been superseded by other contrivances. The simplest, though crudest, is one, it is believed, still extensively used in many places, and consists simply in a can or measure, sometimes detached from and sometimes attached to the boiler; this vessel is filled with water from the boiler at certain intervals for ascertaining the density; the water is allowed to cool down until a certain temperature is obtained, and found by dipping a thermometer into it, and then the hydrometer graduated to that temperature is dipped in, which, by the degree of its immersion, indicates the specific gravity or density of the water. Such an instrument will, of course, fulfil the object of showing the density any time it may be required; but the operation is tedious and requires care, and handling such delicate glass instruments is not exactly the thing in rough weather, when the engineers have many parts of the machinery requiring their constant attention. The next step was the introduction of more practical and complete apparatus, the most commonly known of which is that called How's salinometer. Though not favoured with an illustration of this instrument, its general appearance and construction will be seen from Fig. 3; for if we leave out the long tube, A, in Long's salinometer, the remaining parts show as near as possible the arrangements of How's. His salinometer case contains a separate compartment for the hydronometer and thermometer, and it is easy enough at any time to let in the water from the boiler so as to fill the case; shutting off the communication with the boiler and blowing off the surplus water, if any, the density of the water, when the ebullition has ceased, can be read off. But this ebullition, resulting from the reduced pressure of the atmosphere to which the water in the salinometer case now becomes subjected, causes a quantity of hot water to be thrown out of the case, thus exposing the engineer to be scalded; the sudden rush of water from the boiler, if not properly checked by opening the cock very carefully, tends also to throw the hydrometer with great force against the cover, causing the danger of breaking it; nevertheless, this instrument has been and is still extensively used.

A more complete salinometer than the preceding one is illus-

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trated by Fig. 3. This is the invention of Mr. Long, a chief engineer of the United States Navy. The objections to How's salinometer are obviated in this instrument by the addition of another separate tube, A. This latter contains a smaller internal tube, B, by means of a cock communicating at the bottom with the water in the boiler while the top is closed, but having small openings near the upper extremity, through which the water can escape in the outer compartment of the long tube or vessel, the steam at the same time freely disengaging itself. The long casing communicates at the bottom with the salinometer casing, which is fitted with a thermometer and a hydrometer. By this arrangement the rush of the water and the violent ebullitions are checked, and thus the density of the water can be observed without danger and inconvenience.

But a more convenient and less cumbersome apparatus is represented by Figs. 4, 5, 6, 7, and 8. This salinometer, the invention of Mr. Gamble, chief engineer of the steamer *City of Norwich*, has all the advantages of Long's, while the whole apparatus is contained in one piece, thus offering less obstruction, being more sightly, and taking up less space in the engine-room, besides possessing the great advantage of being very simple in construction and easy to manage. This salinometer is now coming extensively into use, and is being manufactured by Messrs. Hayward, Tyler, and Co., of Whitecross-street.

In Figs. 9, 10, and 11 is shown an improved pattern of the same apparatus. The water is admitted through the side entrance, A, of the four-way cock, into the hollow of that cock, and from there by opening the regulating screw of the jamb valve, B, into the bent copper tube in the salinometer case. At the top of the bend is a hole for letting the steam freely escape. By passing through in this way the force of the water is broken, and it will now enter the larger tube, C, containing the hydrometer, quietly. That tube is cut open on one side, and a corresponding hole is left in the casing, with a glass plate inserted in the same, which shows the density of the water at any time. By the side of the hydrometer tube is a cavity containing the thermometer, the indications of which can likewise be seen through a glass. An overflow pipe, D, carries the surplus water away. Closing the jamb valve occasionally and then blowing through from the boiler enables the engineer to clear the supply pipe from any sediment, and this is an important point. The next operation on starting the salinometer afresh is to blow it through, which can be easily done by opening the jamb valve and setting the handle of the four-way cock so that a line on the dial plate points straight through from the salinometer to the waste pipe; this clears the salinometer, and allows the water in the supply

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pipe time to cool down, before entering the salinometer. 200° Fahrenheit is the temperature the hydrometer is gauged to. By the regulating screw of the jamb valve this can be easily and conveniently obtained as well as retained. Another great advantage in this practical little instrument, though it may not at first sight appear to amount to much, is the arrangement of the scales. The indications are given outside the brass face of the instrument, where they can be read off instantly. In conclusion, there is no doubt that, after all, blowing off in the proper manner is the best means of preserving the boiler; that there cannot be given the engineer facility enough to do so, and that a salinometer possessing the advantages just described, which are fully borne out in practice, forms the best safeguard against the incrustation of marine boilers.

APPENDIX.

LOSS IN HEAT OR FUEL BY BLOWING OFF.

Taking the density of common sea-water at $\frac{1}{32}=3{\cdot}125$ per cent., then half the water requires to be removed to keep the remainder, as the steam leaves its saline matter behind, at a density of $\frac{2}{32}$. Likewise, if a density of $\frac{3}{32}$ is thought sufficient, then $\frac{1}{3}$ of the water must be blown off, and so on. We may assume the temperature of the steam to be the same as that of the water when leaving the same, however much it may afterwards become superheated by a high uptake or by a special superheater. The temperature of boiling salt water is 1·2° higher for the same pressure than fresh water for every $\frac{1}{32}$ of saltness contained in the same, and according to this the following Table is calculated showing the total heat of the steam at various pressures and densities of saltness in the boiler. The temperature of the water is also given; and to get the total heat of the water corresponding, it is only necessary to subtract 32° in each case. The lowest column gives the quantity of water required to be blown off to keep the water in the boiler at the density indicated at the top of the same column. The loss in heat by blowing off can be easily calculated for any pressure and density of saltness, as follows;

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Pressure in lbs. per square inch.	Temperature of water at density of $\frac{14}{32}$	Temperature of water at density of $\frac{2}{32}$	Temperature of water at density of $\frac{24}{32}$	Temperature of water at density of $\frac{24}{32}$	Temperature of water at density of $\frac{24}{32}$	Temperature of water at density of $\frac{3}{32}$	Total heat of steam at density of $\frac{14}{32}$	Total heat of steam at density of $\frac{2}{32}$	Total heat of steam at density of $\frac{24}{32}$	Total heat of steam at density of $\frac{24}{32}$	Total heat of steam at density of $\frac{24}{32}$	Total heat of steam at density of $\frac{3}{32}$
15	252·5	252·8	253·1	253·4	253·7	254·0	1159·9	1160·2	1160·5	1160·8	1161·1	1161·4
16	254·3	254·6	254·9	255·2	255·5	255·8	1160·5	1160·8	1161·1	1161·4	1161·7	1162·0
17	256·2	256·5	256·8	257·1	257·4	257·7	1161·0	1161·3	1161·6	1161·9	1162·2	1162·5
18	258·0	258·3	258·6	258·9	259·2	259·5	1161·6	1161·9	1162·2	1162·5	1162·8	1163·1
19	259·7	260·0	260·3	260·6	260·9	261·2	1162·1	1162·4	1162·7	1163·0	1163·3	1163·6
20	261·4	261·7	262·0	262·3	262·6	262·9	1162·6	1162·9	1163·2	1163·5	1163·8	1164·1
21	263·0	263·3	263·6	263·9	264·2	264·5	1163·1	1163·4	1163·7	1164·0	1164·3	1164·6
22	264·7	265·0	265·3	265·6	265·9	266·2	1163·6	1163·9	1164·2	1164·5	1164·8	1165·1
23	266·3	266·6	266·9	267·2	267·5	267·8	1164·1	1164·4	1164·7	1165·0	1165·3	1165·6
24	267·9	268·2	268·5	268·8	269·1	269·4	1164·6	1164·9	1165·2	1165·5	1165·8	1166·1
25	269·4	269·7	270·0	270·3	270·6	270·9	1165·0	1165·3	1165·6	1165·9	1166·2	1166·5
26	270·8	271·1	271·4	271·7	272·0	272·3	1165·5	1165·8	1166·1	1166·4	1166·7	1167·0
27	272·3	272·6	272·9	273·2	273·5	273·8	1165·9	1166·2	1166·5	1166·8	1167·1	1167·4
28	273·7	274·0	274·3	274·6	274·9	275·2	1166·1	1166·4	1166·7	1167·0	1167·3	1167·6
29	275·1	275·4	275·7	276·0	276·3	276·6	1166·7	1167·0	1167·3	1167·6	1167·9	1168·2
30	276·5	276·8	277·1	277·4	277·7	278·0	1167·2	1167·5	1167·8	1168·1	1168·4	1168·7
Quantity of water to be blown off.	·57	·5	·444	·4	·3636	·333						

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Assume the temperature of the feed-water to be 110°; for a pressure of 20 lbs. per square inch and a saltness of, say, $\frac{2\frac{1}{4}}{32}$ we find the temperature in the boiler to be 262°, the corresponding total heat of the steam is 1163·2°, the quantity of water to be blown off is ·444. Now calling the quantity of feed-water entering 1, that blown off is ·444, and that retained is ·556. The heat imparted to the water blown off is ·444 (262 − 110) = 67·49°, the heat imparted to the steam is ·556 (1163·2° − (110 − 32) = 614·32°; we thus see that the heat lost by blowing off (67·49°) is to the total heat imparted (614·32° + 67·49°), 10 per cent., nearly. Generally speaking, calling the temperature of the water in the boiler t, that of the feed-water t_1, the total heat of the steam T, the per-centage of water blown off x, and that of the water converted into steam y, whence $x + y =$ quantity of feed supplied, the loss in heat by blowing off is $= \frac{x\,(t\ t_1)}{T\,[T\,(t_1 - 32)] + x\,(t - t_1)}$ of feed supplied, the loss of heat by blowing off is =

$$\frac{x\,(t - t_1)}{y\,[T - (t_1 - 32)] + x\,(t - t_1)}.$$

DISCUSSION.

Mr. Olrick said that Mr. Jensen had read a very valuable paper on a most important subject, as the incrustation in marine boilers was the main cause of their lasting so short a time. The chloride of sodium, or common salt, has, at moderate pressures, little to do with the evil of incrustation in marine boilers, whereas sulphate of lime and magnesia are the principal evil-doers, because they form deposits at all temperatures and densities, which is not the case with the salt, as the precipitation first commences at a density of $\frac{4}{33}$, and the point of saturation is not arrived at before $\frac{18}{33}$. He (Mr. Olrick) here exhibited specimens of incrustations taken from marine boilers: the first sample was very thin, although the boiler had been ten months at work, and the ship had run a distance of 30,000 miles; but a Gamble's salinometer had been attached to the boilers the whole time, showing the benefit to be derived from the use of this instrument, which became more apparent when we saw the second sample of incrustation, about $\frac{1}{4}$ in. thick, which had been formed in two months only at a distance run of 7000 miles with no salinometer. He (Mr. Olrick) also showed two specimens of incrustation taken out of a steamer belonging to the Greek and Oriental Steam Navigation Company. In this case the incrustation was formed into a solid block between the tubes, a proof of the scandalous neglect

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that takes place sometimes in steamers. Chloride of sodium is only precipitated by concentration, and this could easily be avoided by blowing off, whereas sulphate of lime was precipitated with a very small amount of concentration hardly avoidable, and also by elevation to a temperature now often used in steamers. The question was how to remove these evils. There were two different ways of doing it, either by separating the impurities from the water before it went into the boilers—which seems by far to be the more rational way than to allow them first to enter and then to have the trouble of removing them again—or by applying different means for freeing the boilers from the incrustation accumulated. To the first class belong the ordinary separators of different descriptions, which, however, nearly all fail, some on account of insufficient time being given to the sulphate of lime to settle, and the consequence was that it did not separate, but entered the boiler; and others, where the exhaust steam was applied for raising the temperature of the feed-water and thus cause a precipitation, failed on account of the heat being insufficient. Separate boilers were also used for heating the water before it entered the main boiler; but these auxiliaries became very soon coated with incrustation, and were thus disabled. The best apparatus amongst the class heated by steam taken direct from the boiler is Martin's, which is a simple, compact, and efficient separator, which ought to be adopted in every sea-going steamer. A member of this Society (Mr. Danchell) has applied Dr. Clark's system of separating the carbonate of lime from fresh water and thus softening it—a very useful and practical apparatus, by which means any number of gallons of water can be softened per hour, according to the size of the apparatus. We now come to the different means for freeing the boilers from the impurities accumulated in them, and first amongst these stands blowing off, either from the bottom of the boiler by means of the ordinary blow-off cock or from the surface of the water by means of a scumming-apparatus; but with bad circulation of the water in a boiler these means are not sufficient to keep the boiler free from the accumulation of scale or sediment, that, generally, in all places on which the fire acts, gets hard and difficult to remove, and it has, therefore, been found necessary to introduce into boilers different compositions, the object of these being simply to loosen scale and to prevent the formation of sediment anew. He (Mr. Olrick) was, however, of opinion, that a good circulation of the water was a very effective means of keeping the heating surface in a boiler clean; and in corroboration of this statement, he (Mr. Olrick) exhibited a patent "Field" tube which had been at work night and day for nine months without cleaning, and still it was now just as clean

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as the day it was put into its place in the flue of a Cornish boiler.

Mr. C. F. T. YOUNG stated that his experience was, that the best apparatus for preventing incrustation could not be relied on unless the men in charge of the boilers gave them proper attention. He believed that the surface-condenser introduced a very serious cause of deterioration in boilers. In sea-going boilers the advantages of surface-condensers were more than counterbalanced by the repairs which became necessary. Boiler compositions were very objectionable. He had not seen one that could be trusted in ordinary use. He believed that the theory was to dose the boiler every day, and the composition fetched off the scale which was formed, but it introduced a very serious difficulty by causing the deterioration of the plates and leakage. If a boiler were to be cleaned out, it certainly would not be objectionable to give it a good dose of some composition the day before; but that should be afterwards thoroughly washed out and got rid of. He did not think that any strict rule to apply to all cases could be laid down with regard to land boilers, either blowing off or pickling, or anything else. The best way was to test the feed-water, and then provide the means necessary to guard against the action of whatever it might contain.

The PRESIDENT said that one of the most important points raised in the paper was that as to the use of surface-condensers. He hoped that there were some present who could give information as to the use of surface-condensers in connexion with marine boilers from actual experience.

Mr. THOMAS ADAMS said that some of the salts contained in sea-water floated on the surface of the water in the boiler. There were two means of getting rid of the floating salts—surface blowing off and the brine-pump. Blowing off did not get rid of the difficulty, and it seemed to him that the only way to grapple with it was by evaporation. He did not agree with the theory stated as to the loss of heat by scale in boilers. The theory was much above the practice. A $\frac{3}{8}$-in. scale, supposing it covered the whole interior of a boiler, would not increase the consumption of coal more than 10 per cent.

Mr. OLRICK said, in answer to the question raised by the President, that he had seen boilers which were supplying steam to Messrs. Maudslay's three-cylinder expansive engines fitted with surface-condensers. These boilers were considerably smaller than those ordinarily supplied for the same horse-power engines. At first they had some trouble with the boilers from using rather too much tallow in the engines, the acid of which seemed to have the effect of corroding the boilers, which were always filled with fresh water when starting and kept supplied with the same through-

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out the voyage, from the surface condensers. But after a small amount of salt water was admitted into the boilers, just sufficient to form a very thin crust on the iron, no corrosion took place. The tallow was, in the first instance, used rather freely to keep all working surfaces from being affected by the highly superheated steam. This point was, however, also soon remedied by mixing the saturated with the superheated steam, and thus lessening its high temperature. There was one point which Mr. Jensen seemed to have forgotten in stating the per-centage lost by incrustation, and that was the decrease of efficiency of the fires, when becoming dirty. When the boilers first started on a trip, all the fires were fully effective, but after being at sea for some 8 to 12 hours, the fires got very dirty and wanted cleaning, and this amounted to a decrease of about one efficient fire out of eight, which would be about 12 per cent. This diminution of heat was often put down as a loss of heat by incrustation, though it was really due to the fires becoming dirty.

Mr. JENSEN: I say in my paper "starting with clean fires."

Mr. OLRICK said that the meeting were left to infer that the clean fires might become dirty. As to blowing off, he believed that the most effective way was blowing off at the surface.

Mr. P. F. NURSEY said that there could be no doubt that incrustation in marine boilers was at one time a perplexing matter to deal with, as it was supposed to be impossible to prevent the boilers of a steamer from becoming salted up in some seas. But it had been ascertained that the saltness of different seas varied but little, and, however salt the water was, the boiler might be preserved from any injurious incrustation by blowing out from the surface. That operation to be effectual should be performed very frequently, or a portion of the supersalted water might occasionally be allowed to escape. By proper blowing out a very slight scale at the most would ever be found. A more complete remedy, however, for incrustation existed in the adoption of surface-condensation, which although an expense at first, would nevertheless prove of incalculable benefit in the end, besides effecting a great saving in fuel and, with land boilers, in water rates. But a step in advance of that was the apparatus M. Emile Martin substituted for the surface-condenser. M. Martin separated the salts held in solution in the feed-water by the aid of superheated steam, the deposit of scale taking place in a chamber connected with the boiler, and not in the boiler itself. Instead of directly introducing the feed-water into the boiler, it was injected in the form of a fine shower through a rose into a casing filled with saturated steam, fed from the boiler. By its contact with the steam the water rapidly acquired a high temperature, which was additionally raised by means of a current of su-

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perheated steam which entered the apparatus in an opposite direction to the water. Some of the water at length became steam, and left its incrustations on perforated plates in the vessel. The steam generated in the vessel flowed into the steam-room of the boiler, while the water which was considerably heated was conveyed to the bottom part of the boiler. By that arrangement the surface-condenser was in effect superseded. With regard to boiler compounds, it might be shown that their name was legion, and they had both supporters and objectors. That arose from the fact that there were instances in which, either from accident or from judicious choice, selection was made of a remedy which proved suitable to the disease. On the other hand, an improper antidote was very often applied, it being frequently supposed that one description of boiler fluid or scale-preventer was applicable in all cases. When water was found to form a rapid incrustation it should be submitted to chemical analysis, the result of which would indicate the proper remedy. Carbonate of soda had been largely used, and with good effect. But, better than all the various crotchets and nostrums, was the plan of using boilers which were properly constructed in the first instance, by which incrustation was reduced to a minimum, if not entirely prevented. By a properly constructed boiler, he (Mr. Nursey) meant one in which the proper circulation of the water was effected. In boilers thus designed, such a thing as scaling was of very rare occurrence. As our boilers were not all properly constructed, then we must take all the preventive measures in our power, among which salinometers were, perhaps, the most valuable. Grease had been found to preserve land boilers from the worst effects of incrustation. In the Royal Gun Factories, Woolwich, the boiler-plates were greased after each cleaning, which facilitated the removal of scale. The refuse oil from the drip-cans of the shafting was collected, and after the boilers were cleaned it was laid on inside them with a brush. Although that did not stop the incrustation, it caused it to come off much more readily, and was found to effect a great saving in time and expense in cleaning the boilers. It was a common practice to throw into boilers old greasy cotton waste under the impression that it facilitated the removal of the scale. But it was open to objection, inasmuch as the oil combined with impurities in the water and formed a greasy substance, which, when precipitated on the plates, prevented contact of the water, and was thus the cause of overheating. The danger attending that practice was illustrated by the explosion of a boiler in October, 1864, and which was purely caused by grease incrustation. It proved beyond dispute that explosions did occur from a cause which was but little believed in. The boiler was cylindrical, with hemispherical ends, and was made of $\frac{3}{8}$ in. plates in 1850, it had two $2\frac{1}{2}$ in. safety

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valves, weighted to blow off at forty pounds. One day, a loud report was heard, the fireman was thrown down, and steam and water issued from the fire-door at the same instant. On examination it was found that about 8 feet beyond the bridge there was a hole in one of the end plates of an irregular triangular form, about 7 in. in length and 4 in. in width at the base. Around the hole on the inside was an accumulation of deposit extending over an area of about 2½ square feet, from 1 in. to 1¼ in. in thickness in the centre, and gradually reducing in thickness towards the outside. In other parts, the boiler was almost free from the deposit, but the surface of the plates had a greasy appearance, and at the back end there was a small patch of deposit of the same kind as that just mentioned. The deposit was found to be composed of grease and earthy matters, and on applying a light it ignited like a piece of wood. The formation of this deposit was due to the introduction of grease, either by the attendant or in the feed-water, which it appeared, at times, conveyed greasy matter from adjacent soap works. The feed-pipe delivered the water about 15 in. from the centre of the hole in the plate on the side nearest the fire, 10 in. from the bottom of the boiler. The feed had been turned on about ten minutes previous to the accident, and the plate showed evidence of its cooling effect on that side. The inevitable conclusion was, that, after the plate had become red hot in consequence of the deposit, the latter had become loosened, and fracture taking place, water had intervened between the deposit and plate, producing a sudden generation of steam sufficient to cause rupture. Before concluding, he (Mr. Nursey) would mention an interesting circumstance in connexion with boiler scale. Dr. T. L. Phipson, F.C.S., had made an analysis of a recently imported mineral substance, which, under the denomination of best India phosphate (under which term, by the way, a variety of phosphatic materials found their way to the agricultural world in England), was said to have been imported from America in large quantities during last summer. It professed to be phosphate of lime, but a mean result of numerous analyses made by Dr. Phipson upon various samples gave the following composition in 100 parts:

		Atomic ratio.
Sulphate of lime	65·00	0.956
Water	13·50	1·500
Magnesia	19·00	0·905
Oxide of iron alumina	0·85	
Chloride of sodium	0·70	
Sand	0·45	
	99·50	

It was not difficult from that to see that it contained all the substances usually found in marine-boiler incrustations. It was

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rather a novel kind of industry to scrape out the boilers of large steam-ships and send the products into commerce as West India phosphate. It certainly showed how important it was that agriculturists should have every new product carefully investigated. It further pointed out that if incrustation were prevented—as it undoubtedly could be—the public would be indebted to the sharpers for one fraud the less. The above analysis led to the formula:

$$(2Ca\,S \times H) + 2Mg\,H,$$

1 atom of "boiler sulphate" + 2 atoms of hydrate of magnesia. 2 Ca S + H is the "boiler sulphate" of the late Professor Johnstone; it was here combined with two atoms of hydrate of magnesia, the hydraulic qualities of which were well known.

Mr. CARGILL said that a mechanical method of removing incrustation had been introduced into France. There was a set of small rakes fixed upon a rod which was capable of a rotatory and a progressive motion. He believed that the inventor proposed that the rod should be worked by machinery when used for large, and by hand when used for small boilers.

Mr. JENSEN said that Mr. Olrick had mentioned $\frac{3}{32}$nds as the proper density to be kept in marine boilers. He (Mr. Jensen) believed that was very commonly used for 10 lb. pressure, but with 20 lb. pressure $\frac{2}{32}$nds is the most common density. A description of Martin's apparatus would be found in the paper when it is published. Another process often patented was to precipitate the salts and then filter the water. The precipitation was effected by introducing certain chemicals, one of which was baryta. The heat lost by blowing off was such an easy matter to find by calculation that he had not gone into it in the paper, and no rule could be laid down, as the loss varied with every temperature and with every density. He had mentioned that in one case it amounted to 14 per cent. That was with blowing off half the quantity of water and keeping the density at $\frac{2}{32}$nds. At $\frac{3}{32}$nds the loss would not amount to anything like that. He would, however, calculate a table for facilitating the calculation. Mr. Young's observation corroborated the general opinion that the circulation had everything to do with incrustation. The temperature of the upper tubes being higher than that of the lower tubes, there was no doubt that there was more rapid circulation and ebullition at the top than at the bottom, and that might account for the greater amount of scale accumulated in the lower part than in the higher. The reason that brine-pumps were introduced was to draw off a certain fixed quantity, the pumps being so proportioned as to draw off exactly that quantity. He believed that the calculation that a $\frac{3}{8}$ths inch scale represented a loss of only 10 per cent. was very erroneous. According to the

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GAMBLE'S

ED PATENT SALINOMETER.

Fig. 9.

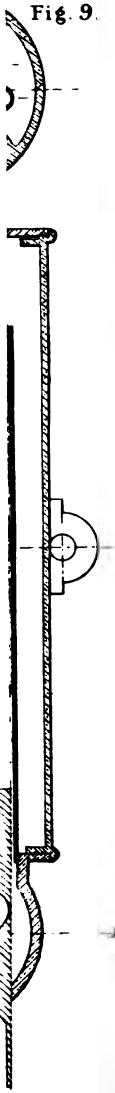
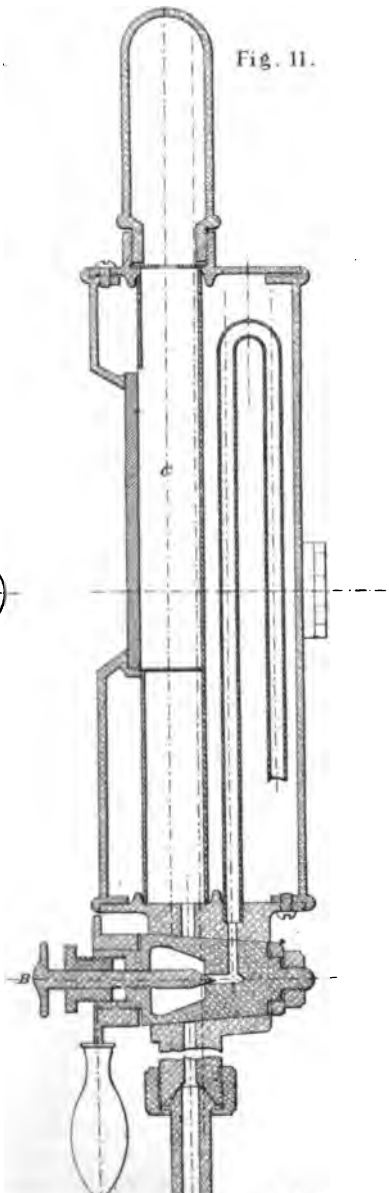


Fig. 11.



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very exact experiments of M. Cousté, as much as 40 per cent. of heat was lost by incrustation; but whether the scale was exactly $\frac{3}{8}$ths of an inch he (Mr. Jensen) did not know.

Mr. OLRICK remarked that no engineer would ever allow a scale to accumulate to such a thickness.

Mr. JENSEN said it might easily be done by mismanagement, and then he believed the loss would be much greater than 10 per cent. As to the crowding of tubes in marine boilers spoken of in the paper, and of which Mr. Olrick mentioned an example, he (Mr. Jensen) might say he had had a case of exactly the same description some years ago. The boiler in question had some twelve or thirteen rows of tubes, one above the other, and with very narrow water spaces. That boiler gave great trouble, especially at the back tubeplate. On being applied to, he (Mr. Jensen) at once recommended the removal of the two or three (he forgot which) upper rows of tubes; the calorimeter also being larger than required. It was subsequently found that this remedy, though seemingly detracting from the evaporative efficiency of the boiler, in reality added to the same, as it was the means of a better circulation, thus keeping the tubes and back tubeplate more free from incrustation, and probably adding considerably to the longevity of at least those parts. He (Mr. Jensen) afterwards exhibited and explained a Gamble's salinometer to the meeting.

The PRESIDENT said it was well known to engineers that there had always been a hitch in the use of surface-condensers. It was so in Hall's time, thirty years ago, and, in consequence of the difficulties that were then found, they went out of use. They had been revived again only within the last few years, and there was a great deal of difference of statement as to what the result of them really was. It was only a year or two ago that Mr. Murray, of Southampton, said that the corrosion of the boilers caused by the condensers cost more than was gained by them. On the other hand, Mr. Spencer said that he had ships running six or seven years without any corrosion at all. The great question was, what to do to prevent incrustation. Mr. Elder said at the United Service Institution that changing the water every five or six days had the effect of preventing it. Surface-condensers were coming into use to a considerable extent for land engines, and those who had used them seemed to speak very well indeed of them. In the United States water-tube boilers were very largely used, for they were much more readily scaled than others. They were known there as marine boilers under the patent of Mr. Montgomery. The principle of the water-tube boiler was a very old idea. John C. Stevens patented it in this country in 1805, and it was very much used in the United States.

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October 1st, 1866.

BALDWIN LATHAM IN THE CHAIR.

ON SINGLE AND DOUBLE RIVETED JOINTS.

BY THOMAS BALDWIN.

ASK a boiler-maker why he places the rivets in a boiler 2 in. apart, and he answers, because "it's the practice"—that is, because it is customary to do so.

Ask the inspector of a boiler association the same question, and he, "with his extensive experience and close observation of many hundreds of boilers," tells you that 2 in. is the best distance, since all boiler-makers use it, and, further, if the rivets be placed at a greater distance apart, the joints cannot be made tight, and, if placed nearer together, the metal left between the rivet-holes will be too weak to bear the strain upon it.

If, then, you say to these gentlemen, it has been found by experiment that a bar of iron 1 in. square used as a rivet will be sheared across by a force of 50,000 lb., and that a piece of boiler-plate having a section equal to 1 square inch will be torn asunder by 51,000 lb., and that you conclude from these experimental facts that the area of the rivet and the area of the cross section of the metal left between the rivet-holes should be nearly equal to make the strongest boiler, you are at once told that "*in theory* it may be so, but it has been found that the plates are so much weakened by the use of the punch that nothing short of 2 in. will do for the pitch of the rivets." If you ask to be referred to experimental data showing that this pitch under all circumstances is the best, you are simply told that experience teaches it, and this even by men placed in a position to advise the users of steam boilers as to the best method of construction.

The writer is, therefore, desirous of placing this matter fairly before those who spend large sums of money on steam boilers and yet get only 75 per cent. of the strength that correct principles of construction will give, and, therefore, pay 25 per cent. more for a boiler than is required if these principles be attended

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to, or get a boiler that is 25 per cent. weaker than it ought to be. However strange it may seem, a boiler made of $\frac{3}{8}$ in. plates and put together with $\frac{3}{4}$ in. rivets and 2 in. pitch is just as strong as a boiler made of $\frac{1}{2}$ in. plates with the rivets and pitch the same as used for the $\frac{3}{8}$ in. plates, for both would give way by the rivets being sheared across, which causes the user of a boiler to pay 25 per cent. more for his boiler than he ought to pay.

We will now try to ascertain and confirm by mathematical demonstration what ought to be the proper pitch to get the strongest riveted joints for steam boilers from the least material when the thickness of plates and the diameter of the rivets are given.

As mathematical demonstration is by far the shortest and simplest way of arriving at the required result,

Let P = pitch of the rivets in inches.

d = diameter of the rivets in inches.

a = area of one rivet in inches.

t = thickness of plates in inches.

s = number of pounds required to shear 1 square inch of wrought iron in the form of rivets.

n = number of pounds required to tear asunder 1 square inch of the boiler-plate left between the rivet-holes after punching.

Then the sectional area of the plate between any two rivet-holes is

$$=(P-d)\,t,$$

and the force required to tear that section asunder is

$$=(P-d)\,t\,n \quad . \quad . \quad . \quad . \quad . \quad . \quad (1).$$

The force required to shear one rivet across is

$$=as \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2).$$

Now, to economise material, and make the strongest single-riveted joint, we must make the rivets just on the point of shearing across when the plates are just on the point of being torn asunder; therefore (1) and (2) must be equal, or

$$(P-d)\,t\,n=as \quad . \quad . \quad . \quad . \quad . \quad . \quad (3);$$

from which we get

$$P=\frac{as}{tn}+d \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4),$$

and

$$n=\frac{as}{(P-d)\,t} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5).$$

Now, Mr. Fairbairn has given a table for practical use, in which the thickness of the plates, the diameter of the rivets, and the pitch of the rivets are stated.

Making $s=50{,}000$ lb., which has been arrived at by experi-

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ment and given on the authority of Professor Rankine, and making P, d, and t agreeable to Mr. Fairbairn's table, we find by equation (5) the values of n in Table I., column 5, as below:

TABLE I.

Given in Mr. Fairbairn's Table.				By equation (5).
Plate t.	Rivet d.	Pitch P.	a.	n.
$\frac{3}{16}$	·375	1·25	·11044	33670
$\frac{1}{4}$	·500	1·50	·19635	39270
$\frac{5}{16}$	·625	1·625	·3068	49088
$\frac{3}{8}$	·75	1·75	·4417	58893
$\frac{1}{2}$	·8125	2·00	·51849	43666
$\frac{5}{8}$	·9375	2·50	·6903	35346
$\frac{3}{4}$	1·125	3·00	·994	35343

The values of n shown in the last column are very variable indeed, attaining a maximum in the case of $\frac{3}{8}$ in. plates amounting to 58,893 lb., while the experiments made by Mr. Fairbairn on the tensile strength of boiler-plates, and given in his paper read before the Society of Arts in November, 1864, gives the mean value of $n = 52{,}486$ lb.; and yet we find the values of n as deduced for $\frac{1}{2}$ in. plates from Mr. Fairbairn's table amounting only to 43,666 lb., and for $\frac{1}{4}$ in. plates as low as 39,270 lb.—a discrepancy quite unaccountable.

The common practice of making the distance between the rivets 2 in. for $\frac{3}{8}$ in. plates with $\frac{3}{4}$ in. rivets gives by equation (5) the value $n = 51{,}041$ lb., which is a close approximation to the strongest form of joint for single-riveted plates.

If n be taken of the same value as Mr. Fairbairn recommends for $\frac{3}{8}$ in. plates, we have by equation (4)

$$P = \frac{as}{tn} + d = \frac{\cdot 4417 \times 50000}{\cdot 5 \times 58893} + \cdot 75 = 1\cdot 5 \text{ in.} \quad . \text{ (A).}$$

But if the pitch of the rivets for $\frac{3}{8}$ in. plates be 2 in., then $n = 51{,}041$ lb.; with $\frac{3}{4}$ in. rivets and $\frac{1}{2}$ in. plates we get

$$P = \frac{\cdot 4417 \times 50000}{\cdot 5 \times 51041} + \cdot 75 = 1\cdot 615 \text{ in.} \quad . \quad . \text{ (B).}$$

Mr. Fairbairn gives a number of experiments on single-riveted joints (in the "Philosophical Transactions" for the year 1850, and in his "Useful Information for Engineers"), the thickness of the plates used being ·22 in. and 3 in. broad, put together with $\frac{1}{2}$ in. rivets.

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The mean breaking weight of all the experiments is given at 18,590 lb.

The area of the two rivets being $2 \times \cdot 19635 = \cdot 3927$, and the sectional area of the plates after punching $= (3-1)\ \cdot 22 = \cdot 44$, from which we get

$$n = \frac{18590}{\cdot 44} = 42250 \text{ lb.},$$

which being used for $\frac{1}{2}$ in. plates with $\frac{3}{4}$ in. rivets, we have, by (4),

$$P = \frac{\cdot 4417 \times 50000}{\cdot 5 \times 42250} + \cdot 75 = 1 \cdot 795 \text{ in.} \quad . \quad . \text{ (C).}$$

Mr. Fairbairn's experiments with plates ·22 in. thick, $3\frac{1}{2}$ in. broad, fastened together with three rivets $\frac{1}{2}$ in. in diameter, gives

Area of the three rivets . . . = ·589 in.
Area of plates, deducting rivet-holes = ·44 in.,

which broke through the line of rivets by 19,675 lb., giving

$$n = \frac{19675}{\cdot 44} = 44534 \text{ lb.}$$

Had these plates been 4·178 in. broad instead of 3·5 in., the section of the plate after punching would have been $2 \cdot 678 \times \cdot 22 = \cdot 589$, equal to the area of the three rivets, and the riveted joint much stronger, the ratio of strength being nearly as 100 to 84.

But experiments made on only two or three rivets is no fair criterion, as Mr. Fairbairn has suggested; for he concludes that the strength of a single-riveted joint, including the rivet-holes in the measurement of the section of the plate, is fairly represented by a breaking strain of 34,000 lb. on the square inch of such section.

Now, the entire section of the plate used in the experimental inquiry with two rivets was $3 \times \cdot 22 = \cdot 66$ in., and the section of the plate, after deducting the rivet-holes, will be $(3-1) \cdot 22 = \cdot 44$ in.; we then have $n = \frac{34000 \times \cdot 66}{\cdot 44} = 51{,}000$ lb. as the power of the riveted plates to resist a tensile strain.

Applying this value of n as before, we find, for $\frac{1}{2}$ in. plates and $\frac{3}{4}$ in. rivets,

$$P = \frac{\cdot 4417 \times 50000}{\cdot 5 \times 51000} + \cdot 75 = 1 \cdot 616 \quad . \quad . \quad . \text{ (E).}$$

The mean of these results for $\frac{1}{2}$ in. plates will be found to give $P = 1 \cdot 63$ in.

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We therefore find that the shearing force and the tensile force are so nearly equal, that, for practical purposes, they may be considered so; we can then dispense with s and n in equation (4), which becomes

$$P=\frac{a}{t}+d \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6).$$

Which gives, for $\frac{1}{2}$ in. plates and $\frac{3}{4}$ in. rivets,

$$P=\frac{\cdot 4417}{\cdot 5}+\cdot 75=1\cdot 6334 \text{ in.},$$

nearly the same value as the mean of all the other deductions.

After Mr. Fairbairn has analysed his experiments, he says: "If we take the mean of the experiments as respects the area of the rivets to that of the plates, we find one-half in rivets about the proportion, or the area of the rivets in the last experiments should have been ·4 in., which is nearly equal to the area of the plates through the rivet-holes."

The following note is also attached: "Subsequent experiments made for ascertaining the strength of rivets (*vide* experiments on the strength of rivets for the Britannia and Conway tubular bridges) fully corroborate these views, namely, that riveted joints exposed to a tensile strain are directly, or nearly so, as their respective areas, or, in other words, the collective areas of the rivets are equal to the sectional area of the plate taken through the line of rivets."

Again, in his paper read before the Society of Arts (November, 1864), he says: "In this estimate we must, however, take into consideration the circumstances under which the results are obtained, as only two or three rivets came within the reach of experiment; and, again looking at the increase of strength which might be gained by having a greater number of rivets in combination, and the adhesion of the two surfaces in contact, which, in the rivet-joints compressed by machines, is considerable, we may fairly assume the following relative strengths as the value of plates with their riveted joints:

Taking the strength of the plate at . . . 100,
The strength of the single-riveted joint will be . 56."

Now, we find, by equation (6), for all practical purposes, s and n are so nearly equal that they may be neglected, and that

$$P-d=\frac{a}{t} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7).$$

Then we have $100 : 56 :: P : P-d$; but it has been shown that the area (a) of the rivet must enter into the calculation, and if we substitute the equivalent of $P-d$ from (7), we get

$$100 : 56 :: P : \frac{a}{t};$$

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$$\therefore \quad P = 1{\cdot}7857\frac{a}{t} \quad . \quad . \quad . \quad . \quad . \quad (8),$$

which, for $\frac{1}{2}$ in. plates and $\frac{3}{4}$ in. rivets, gives

$$P = 1{\cdot}7857\frac{{\cdot}4417}{{\cdot}5} = 1{\cdot}5774 \text{ in.} \quad . \quad . \quad . \quad (F).$$

Or, substituting the value $\cdot 7854\, d^2$ for a in (8), we have

$$P = 1{\cdot}4\frac{d^2}{t} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9).$$

This expression for the distance of the rivets is therefore deduced from Mr. Fairbairn's estimate of the whole of his experiments, and gives values differing from Mr. Fairbairn's table given in his paper, and before quoted.

Now, Mr. Fairbairn gives distances for rivets which, he states, he finds the best in practice, yet, at the same time, they do not agree with his deductions from experiment.

No one will doubt the importance of having the shells of boilers made of the strongest possible construction.

When the single-riveted joint is used, and the thickness of the plates and diameter of rivets given, we have seen that the true pitch of the rivets is given sufficiently near for practical purposes by equation (6), and also again as deduced from Mr. Fairbairn's estimate of his own experiments by equation (9).

A Table, giving the pitch and diameter of the rivets and the thickness of plates, will be found below, containing the results of both these investigations.

TABLE II.

Thickness of the plates in inches.	Diameter of the rivets in inches.	Area of the rivets in inches.	Pitch of the rivets in inches. Equation (6).	Pitch of the rivets in inches. Equation (9).
t.	d.	a.	$P = \frac{a}{t} + d$.	$P = 1{\cdot}4\frac{d^2}{t}$.
$\frac{1}{4} = {\cdot}25$	$\frac{1}{2} = {\cdot}5$	·1963	1·2854	1·4025
$\frac{5}{16} = {\cdot}3125$	$\frac{5}{8} = {\cdot}625$	·3068	1·6067	1·7528
$\frac{3}{8} = {\cdot}375$	$\frac{3}{4} = {\cdot}75$	·4417	1·9278	2·1033
$\frac{7}{16} = {\cdot}4375$	$\frac{3}{4} = {\cdot}75$	·4417	1·7596	1·8031
$\frac{7}{16} = {\cdot}4375$	$\frac{13}{16} = {\cdot}8125$	·5185	1·9976	2·1159
$\frac{1}{2} = {\cdot}5$	$\frac{3}{4} = {\cdot}75$	·4417	1·6334	1·5774
$\frac{1}{2} = {\cdot}5$	$\frac{13}{16} = {\cdot}8125$	·5185	1·8496	1·8513
$\frac{1}{2} = {\cdot}5$	$\frac{7}{8} = {\cdot}875$	·6013	2·0776	2·1471
$\frac{9}{16} = {\cdot}5625$	$\frac{13}{16} = {\cdot}8125$	·5185	1·7343	1·6456
$\frac{9}{16} = {\cdot}5625$	$\frac{7}{8} = {\cdot}875$	·6013	1·9439	1·1086
$\frac{9}{16} = {\cdot}5625$	$\frac{15}{16} = {\cdot}9375$	·6903	2·1647	2·1910
$\frac{5}{8} = {\cdot}625$	$\frac{15}{16} = {\cdot}9375$	·6903	2·0420	1·9729
$\frac{5}{8} = {\cdot}625$	$\frac{16}{16} = 1{\cdot}$	·7854	2·2566	2·2436

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The fourth column of the last Table seems to be entirely trustworthy as to the pitch of the rivets, since the relations of the strains are more uniform than would be the case if the formula of the last column were used.

Where the holes are punched, their mean diameter should be taken in fixing the pitch, as the taper of the hole reduces the area of the metal between the rivet-holes; and it is only necessary to increase the pitch by the amount the mean diameter exceeds the diameter of the punch.

Double-riveted Joints.

As double-riveted joints are made up of two parallel rows of rivets, we have to determine first the distance from centre to centre of rivets measured along the rows, and, secondly, the distance between the centres of the two parallel rows of rivets.

Mr. Fairbairn gives the pitch, or distance, between the centres of the rivets for double-riveted joints the same as for single-riveted joints, but that distance, the writer presumes, is measured diagonally from one row of rivets to the other, so as to form two rivets in one row and one in the other into an "isosceles triangle," and the distance apart of the two rows of rivets can only be determined by knowing that the lap for double-riveted joints is to be one and three-quarter times the lap of a single-riveted joint, and placing the two rows of rivets at the same distance from the edge of the plate as for single-riveted joints.

Now, if we so place the two rows of rivets that they shall form a number of isosceles triangles, they will, when measured diagonally, and having equal distances apart, have the following values.

Make P equal the pitch of the rivets in each row as before, and D the distance they are apart measured diagonally, and D_1 the distance between the two rows of rivets, and all the other values the same as before, then

$$(P-d)\,t$$

represents the sectional area of the plate between the rivet-holes in each row of rivets, and

$$(P-d)\,tn \quad . \quad . \quad . \quad (10)$$

the force required to tear that section asunder.

The rivets to be sheared across by the force that would tear the last-named section asunder are two in number, and this force is represented by

$$2as \quad . \quad . \quad . \quad . \quad (11),$$

and as before, in the case of single-riveted joints, the values indicated by (10) and (11) must be equal, that is,

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$$(P-d)\,tn=2as.$$

But is has been shown before that s and n are equal; hence

$$P=\frac{2a}{t}+d \quad . \quad . \quad . \quad . \quad . \quad (12),$$

the distance the rivets ought to be apart to ensure the strongest and most economical structure.

The sectional area of the plate between the rivet-holes, taken diagonally, according to the principles of *stress*, need not be greater than half that of the plate between the rivets of each row, that is

$$D-d=\frac{P-d}{2}.$$

Therefore

$$D=\frac{P+d}{2} \quad . \quad . \quad . \quad . \quad . \quad (13);$$

and by substituting the value of P from (12) into that of (13), we get

$$D=\frac{a}{t}+d \quad . \quad . \quad . \quad . \quad . \quad (14).$$

If we make the distance between the two rows of rivets one-half the distance of the pitch of the rivets measured longitudinally, we shall get D rather in excess of the above value (14), and approximate very closely to the experimental form with double-riveted joints made by Mr. Fairbairn.

The Table I. applies equally to double and single riveted joints, since Mr. Fairbairn gives the pitch of the rivets the same for one as the other, although it is difficult to see why, since the strength of the double-riveted joint depends entirely on the proper proportion of the pitch of the rivets in each row to the diameter of the rivets and the thickness of the plates, and not on the distance between the two rows of rivets, or the diagonal distance of those rivets, so long as the last two distances are not so small as to cause the plates to be torn or sheared asunder diagonally. Any excess above these distances only adds to the cost and weight of the structure, without increasing its efficiency.

In Table II., the fourth column gives the pitch of the rivets for single-riveted joints, and by comparing equation (6), from which that column is computed, with equation (12) for double-riveted joints, we find that it is only necessary to add $\frac{a}{t}$ to the values of P, in the Table, in order to obtain the correct pitch of the rivets for double-riveted joints.

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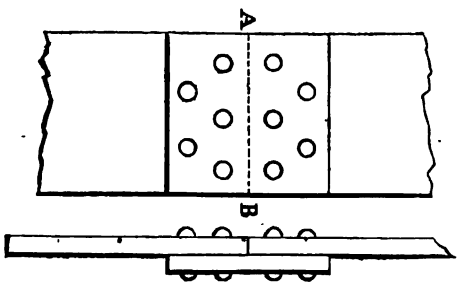
Taking experiments, Nos. 38 and 39, Table X. of Mr. Fairbairn's experiments on double riveting as the most conclusive, we find that the thickness of the plates are ·22, the diameter of the rivets three-eighths = ·375, the breadth of the plates 3·125 in., the main breaking weight 23,707 lb., fracture taking place across the rivet-holes A B.

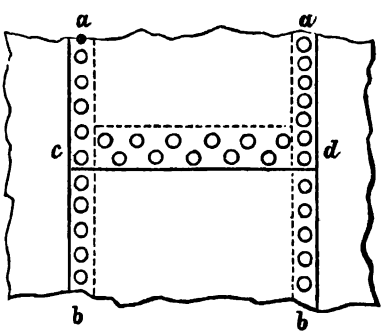


In these experiments there are five rivets to shear across, and the sectional area of the plate, deducting the rivet holes across A B, should equal the area of the five rivets, that is

$$\cdot 11044 \times 5 = \cdot 5522,$$

and $(\cdot 5522 \div \cdot 22) + 3d$ = the width of the plate to be of the strongest form, d being the diameter of the rivets, from which we get 3·635 in. as the width of the plate, whereas the experimental plate was only 3·125 in.

Now, to have been in accordance with double-riveted joints as used in practice, the experiment should have been on six or any other even number of rivets, if the object be to determine the distance or pitch of the rivets. As an example, take the shell of a steam boiler; the direction of the rivets passing round



the shell is shown at a b, and the double or longitudinal rivets

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at *c d*. The distance of the rivets in each row of the double-riveted joint will then be given by the equation (12), as before stated.

In circular steam boilers with two flues, the strain on the riveted joints is very variable, for whilst the joints that run parallel to the axis of the shell have a strain upon them of three units, the joints that pass around the circumference of the shell have only a strain of one unit upon them—hence this class of boiler should have the longitudinal joints double riveted, and the other single riveted, when, owing to the rings of rivets passing round the boiler on each edge of every set of plates and the double-riveted longitudinal joints, the boiler would be as strong with this combination as if the whole were made of solid rings of plates, provided the plates are not made too wide.

The common practice of boiler-makers in Lancashire and Yorkshire is to use 2 in. pitch and $\frac{3}{4}$ rivets, whether the plates be $\frac{3}{8}$, $\frac{7}{16}$, or $\frac{1}{2}$ in., which cannot be too much condemned; yet we find chief engineers of boiler associations stating that this is the correct method of constructing steam boiler riveted joints, although experiments decide to the contrary.

DISCUSSION.

Mr. PENDRED said, the character of Mr. Baldwin's paper was such that he took it for granted that it was not necessary to confine the discussion to questions concerning the strength of riveted joints alone, but that it might include any points of general interest connected with the manufacture or strength of boilers. He had listened very attentively to the paper, and he confessed he was somewhat at a loss to understand anything from it but this. Mr. Baldwin lays down a proposition, that a $\frac{3}{8}$ plate is the best which can be used in a boiler, for he says: "The writer is, therefore, desirous of placing this matter fairly before those who spend large sums of money on steam boilers, and yet get only 75 per cent. of the strength that correct principles of construction will give, and, therefore, pay 25 per cent. more for a boiler than is required if these principles be attended to, or get a boiler that is 25 per cent. weaker than it ought to be. However strange it may seem, a boiler made of $\frac{3}{8}$ in. plates and put together with $\frac{3}{4}$ in. rivets and 2 in. pitch is just as strong as a boiler made of $\frac{1}{2}$ in. plates with the rivets and pitch the same as used for the $\frac{3}{8}$ in. plates, for both would give way by the rivets being sheared across, which causes the user of a boiler to pay 25 per cent. more for his boiler than he ought to pay." He also assumes that a 2 in. pitch is invariably used for all sorts of plates, and he appears to pronounce it bad practice. Yet, in the tables given at the conclusion of his paper, he sums up the results obtained from formula which he puts forward as correct; and

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in this table we have the pitch for $\frac{3}{8}$ in. plates agreeing to a minute fraction with the practice to which he takes exception—$\frac{3}{8}$ in. plates, $\frac{3}{4}$ rivets, pitch 1·9278 deduced from equation (6), and pitch 2·1033 deduced from equation (9). That is practically 2 in. pitch. Now, he (Mr. Pendred) objected, in the first place, to the assumption that 2 inches was the invariable pitch used; and in this respect he had no doubt many gentlemen present would agree with him. He did not object to this pitch himself, and he believed it answered for an ordinary thickness of plate as well as any other a little larger or a little smaller. In the Staffordshire mining districts great numbers of boilers are made yearly, and the pitch with a $\frac{7}{16}$ plate there is sometimes as much as $2\frac{1}{2}$ in., and seldom less than $2\frac{1}{4}$ in. The reason is obvious. The greater part of the money spent on the workmanship of a boiler is devoted to punching and riveting, and the fewer holes there are to be punched, and the fewer rivets to be driven, the cheaper the boiler will be. For $\frac{7}{16}$ plates the rivets are usually $\frac{13}{16}$ths in diameter; when spaced but 2 inches asunder, $\frac{3}{4}$ths. He was not putting these forward as good proportions; but only wished to show that a 2-inch pitch is by no means invariably adopted. And we need not confine ourselves to Staffordshire for an illustration of this fact. On the London and North-Western Railway, he believed he was correct in stating that the usual proportions adopted in express engines were $\frac{7}{16}$ Lowmoor plates in the barrel of the boiler, $\frac{3}{4}$ rivets, spaced $1\frac{3}{4}$ in. apart. In marine work, again, a pitch of $2\frac{1}{4}$ in., with $\frac{11}{16}$ rivets and $\frac{3}{8}$ plate, is very commonly adopted. He need not occupy time by illustrating facts which must be familiar to every one present; and he would proceed to show that, in his opinion, Mr. Baldwin's calculations were, like all other empirical formulæ, more or less imperfect. It will be found on examination that the author had based his figures on the assumption that a boiler joint could only give way by ripping the plate or shearing the rivet; and also that the quality of the iron in the rivets must be the same as that in the boiler, a condition which is by no means always present. Now, it is not an uncommon practice to use ordinary Staffordshire plates and the best Lowmoor rivets. He had done it himself with good results; and it was found that by such a practice even a trifling saving might be effected in the price of the boiler as compared with common rivets, because the rivets were more easily worked. Would Mr. Baldwin affirm that in such a case as this his tables would be applicable? He (Mr. Pendred) thought not. Lowmoor rivets are used, purposely to permit the pitch to be increased; and, owing to the kindly nature of the iron, the riveting is effected with less labour and in less time, and the work is in every respect more satisfactory. But it is clear that a pitch which would be correct for Staffordshire rivets must be wrong for Bowling or Lowmoor rivets, the diameters

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remaining the same. Mr. Baldwin further states that at pitches greater than 2 inches it is difficult to keep a boiler steam-tight. Much will depend on the workmanship, on the size of the rivet-head and point, and on the diameter of the rivet, which has more to do than merely resist shearing; still more on the purpose for which the boiler is intended, and not a little on the pressure. Thus, close riveting is more necessary in a locomotive boiler, undergoing continual strains and jars, than in a Cornish boiler, generally put to work in a mass of brickwork. Further, it is not clear that a boiler must give way by shearing or tearing; on the contrary, he knew of instances where the heads came off the rivets, and the rivets drew. Of course the punching had not been properly managed, and the countersink came at the wrong side of the plate, so that there was nothing to detain the rivet but its head; and this illustrated, he thought, a great defect which must exist in drilled holes, namely, the absence of the countersink. Mr. Baldwin, when maintaining that, by purchasing a $\frac{7}{16}$ instead of a $\frac{1}{2}$ boiler, we spend 25 per cent. more than we ought, completely overlooked the fact that thick plates are required for other purposes than to resist pressure; and his statement was, therefore, erroneous. Boilers almost invariably fail from corrosion; and after everything has been said which can be said about joints, we find that, as a rule, boilers hardly ever fail at a seam, unless the plates in the neighbourhood are corroded or furrowed. Other things being equal, a boiler with a $\frac{7}{16}$ plate will last longer under destructive influences than one $\frac{3}{8}$ thick; and in many instances it will be found that the expenses for the repairs of a $\frac{3}{8}$ boiler will be greater, and the loss caused by its being of necessity thrown out of work to effect them, will come to much more than the 25 per cent. which Mr. Baldwin thinks might be saved. He should like to hear something as to the relative cost in practice of boilers as made in the ordinary way and with butt-joints and welds, either single or double. He should also like to hear something of the results obtained from cold riveting, as practised in the States, and whether it has been tried in this country or not. He understood that in the States the use of the cold-rivet system is very general. Mr. King, of the U.S. navy, states, that although on the seaboard hot rivets are always used, yet that west of the Alleghanies, as at Pittsburg, Louisville, &c., all rivets are driven cold. For the cold process it is claimed that the holes are better filled than when hot rivets are used, as there is no diametrical contraction, and that none but the best iron can be used, as if otherwise it is sure to crack through the head; each rivet is thus tested separately and efficiently. In the western river boats, where excessive pressures are used, no diffi-

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culty is experienced in making tight joints thus. He could not say whether the system had been extensively used in locomotive work. In conclusion, he would point out that it is of even more importance that a boiler seam should be tight than that it should be strong. Leakage is a fruitful source of corrosion, and once this has proceeded to any extent the value of the best seam is reduced to that of the worst.

Mr. Barnaby said that he had heard the paper with a little surprise. He did not know very much about boilers, but he had some experience with riveted joints in ships. He would state the result of this experience in Staffordshire and other description of ship plate iron. The plates of which he was about to speak were not, it must be remembered, of Bowling iron. Bowling iron plates had the peculiarity of having more nearly equal strength with and across the grain than most other iron had. The writer started by saying, and he (Mr. Barnaby) thought very fairly, that Mr. Fairbairn's arrangement for the pitch and size for rivets, and his theory, as the result of his various experiments, were not consistent with each other. Mr. Fairbairn said: "It was ascertained, by direct experiment, that the shearing or cutting the rivets when tearing the joint asunder was as nearly as possible as the areas of the rivets, and the area of the plates respectively taken through the line of the rivet-holes." And Mr. Baldwin came to the same conclusion, namely, that the iron between the rivet-holes in single riveting was as good as the iron in the rivet itself. In all the experiments with which he (Mr. Barnaby) had been concerned he had found that that was a long way from being true, and that the iron between the rivet-holes was most seriously injured by the punching. Mr. Fairbairn stated that in five experiments with lapped plates single-riveted with three rivets, the mean strength between the rivets was 18·9 tons per square inch. That was not equal to the strength per square inch of Bowling rivets, which would be 22 tons. He (Mr. Barnaby) found that a ¾ in. rivet sheared, including friction, at 10 tons a rivet. It was customary among shipbuilders to use tons instead of pounds in these calculations, because there were such great differences between the qualities of iron that nice measurement by pounds was of no practical use. He acted on the principle that a ¾ in. rivet was worth 10 tons, and other rivets equal to what would be given by the proportion of the square of the diameters. The whole question turned upon what was the value of the iron between the holes. The strength of a solid plate of the same iron, said Mr. Fairbairn, was 25·8 tons per square inch. When the holes were punched it was worth 18·9 tons, so that, exclusive of the loss by punching away the iron for the three holes, the iron was weakened about 25 per cent. in the jointing. He next took flush butt joints with single

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covering plates and with three rivets. Here he found the iron between the rivets still weaker than in the laps. It came out only 16·6 tons per square inch, which was 35 per cent. below the strength of plate not having rivet-holes in its neighbourhood. All his (Mr. Barnaby's) experience confirmed that fact, that plates united by strips were not so strong as plates united by laps. There was a very good reason for it, which probably suggested itself to most engineers. Some experiments were made by Lloyd's committee to ascertain the value of different descriptions of riveting. He did not know whose iron they used, but it must have been very bad. He would quote the results, to show how very unsafe it was to argue about iron as if it was all of the same quality, and would always give the same results. That was just what it would not do. This principle he thought they might lay down safely, that they could trust to a rivet better than they could trust to the iron between the rivets. In all the experiments he had made with the Bowling iron he got about the 10 tons, and he had ascertained the additional fact that Brown's steel $\frac{3}{4}$ in. rivets were worth about a ton and a half more. In the experiments made at Lloyd's, instead of the iron breaking at 24 and 25 tons per square inch in double riveting, as it did in Mr. Fairbairn's experiments, it broke at 4 tons, and in thirty experiments it did not once reach 10 tons per square inch. It would be said it was very bad iron, but, nevertheless, it was the iron which was put into ships, though, perhaps, they would say never into boilers. In a number of experiments recently made by the Admiralty at Chatham Yard it was found that when two pieces of $\frac{1}{2}$ in. plate from $1\frac{1}{8}$ in. to $1\frac{1}{4}$ in. wide, and with a lap of from $1\frac{1}{8}$ in. to $1\frac{1}{4}$ in., so as to bring the breaking strength of the iron round the single $\frac{1}{2}$ in. rivet with which they were connected down to the shearing strength of the rivet itself, the iron, which should have stood 21 tons per square inch, broke at the following strains per square inch: 13·6, 13·2, 14·4, 12·4, 12·8, 13·2, and 13·2, or a mean of 13·2, which represents a loss of 37 per cent. arising merely from the injury done to the remaining iron by the existence of the hole in its neighbourhood. Therein lay the great benefit of double riveting—a point which has been passed over altogether in the paper, and, as it seemed to him, by Mr. Fairbairn also. It lay in the fact that the iron between the holes when it was double riveted was not weakened so much as when it was single riveted; because the line of holes through which it was obliged to break was farther away from the edge. In an experiment he made the other day he took a piece of half-inch plate and united it by three $\frac{3}{4}$ in. rivets, three diameters from centre to centre, the plate being across the rivets 9 diameters wide. He had, therefore, to break $2\frac{1}{4}$ square inches. The iron was united cross-

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wise. Of course, as he need hardly remark, they had to attend in boiler-making to the crosswise strength of the plate, and not to the other strength, as it was of no use to have the plate stronger in one direction than in another. When the holes were punched, the piece of plate broke at 10·9 tons per square inch between the holes. It was a very good piece of iron, standing 20¾ tons per inch in the unperforated plate. When the holes were drilled, the iron broke at 11¾ tons. That was a small difference. The difference was usually greater than that, and in steel it was greater still. These results showed how much the iron between the holes was injured. If they could only get some way of welding the plates together, it would be a splendid thing. He considered the statement of Mr. Baldwin in reference to strength was quite wrong. It had been said by previous speakers that there was an advantage gained by thickening the plates beyond that which was got from mere structural strength; but taking the structural strength only, suppose the iron between the holes crosswise were taken as 12 tons per square inch, then the iron between the holes in a ⅜ in. boiler-plate, with ¾ in. rivets and 2 in. pitch, would be worth only 5½ tons, against 10 tons for the rivet. The crosswise strength would generally be taken at more than 12 tons, but never more than 16 tons. Some of the experiments he had recounted gave a lower result than 12 tons. If it were taken at 16 tons, the iron between the holes would be worth only 7½ tons against 10; but with a ½ in. plate, suppose the iron to be worth 12 tons, then the strength would be 7½ tons, and if worth 16 tons would be 11 tons, between the holes. With regard to pitch, he believed that in order to make a *water-tight* joint, ⅜ in. plates having ¾ in. rivets might have a pitch of nearer 3 in. than 2 in. It seemed to him that they acted wisely who kept to at least 2 in. in their boiler work, and that the practice condemned by Mr. Baldwin was quite correct.

Mr. Olrick asked how Mr. Barnaby accounted for the superiority of the iron when the holes were drilled instead of being punched.

Mr. Barnaby said that it seemed to him that the superiority was due mainly to the fact that the punch broke iron in the neighbourhood of the hole, and the drill did not.

Mr. Pendred inquired whether Mr. Barnaby found that the shape and condition of the punch made any difference in the strength of the iron.

Mr. Barnaby said he had not been able to detect differences of that kind. The same punch had been used in each set of experiments. There was always a good clearance in the die.

Mr. Olrick observed, that generally the punching machines in a ship-yard were in such a state that it would be next to im-

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possible to use them for steam-boiler work. In many cases they did not do justice to the iron. There was generally too much clearance, and the iron was torn apart.

Mr. BARNABY replied, that most of the experiments referred to by him were made by new tools in the Government establishments, and the tools were in good order.

Mr. ROBERTS said that, having tried experiments for the last nineteen years upon riveted joints, perhaps he might be allowed to give his formula for making boilers. It was a very simple one, namely, twice the thickness of the plate for the diameter of the rivet, and twice and a half the diameter of the rivet for the pitch. With regard to Mr. Pendred's remarks as to rivets being knocked down hot or cold, he (Mr. Roberts) had had rivets of various lengths riveted hot and then planed down to the centre in the planing-machine, and he always found that when the length of the hole was three times the diameter of the rivet, it invariably, in cooling, shrank in the middle and did not fill the hole; and, therefore, when that proportion was adopted, the rivet should always be knocked down cold. He believed that Lloyd's tests were worth very little indeed. They were tried upon a machine which, to his own knowledge, would not indicate within a ton and a half. His own experiments had been conducted with a machine so sensitive that it would indicate to a pound. As to the bad punching of holes, he must confess that some of the best punched holes he had ever seen were made in a shipyard. A great deal depended upon whether the punch was in good order, and the speed with which the hole was made. With a sharp tool and a good speed, they might get a hole of nearly a fair taper. In the Great Eastern, the holes were punched so that when the rivet was knocked down it would be a double cone, and still hold though the head might jump off.

Mr. PENDRED asked whether Mr. Roberts had tried any experiments as to the proper speed for the punch.

Mr. ROBERTS replied that he had not; but he should be happy to do so before the next meeting.

Mr. PENDRED said he wished Mr. Roberts could also tell them the relative cost of drilled and punched holes. It seemed to him that if the holes had to be rymered and countersunk it would be a very expensive job.

Mr. ROBERTS said that in some boilers for steam fire-engines he had just made, the drilling and countersinking had cost only about three shillings extra. After the holes were fairly drilled, they were countersunk. In reply to Mr. Olrick, Mr. Roberts further stated that he had had very little experience in machine riveting; and that he preferred the method of riveting in the sample produced to snap-riveting, because it closed the plates better than snap-riveting did.

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Mr. CARGILL had seen plates sheared across which had been joined by machine riveting, and he could hardly tell the rivets from the plates, as they were almost incorporated one with the other. That result was frequently not attained by hand riveting. Another advantage of machine riveting was that it overcame the difficulty of keeping the axis of the rivet exactly opposite each head, and equalised the drawing power of the rivet, and made the drawing on each surface of the plates uniform. It had been disputed whether there was any real advantage in filling up the holes, provided the joints were tight. He could not agree with Mr. Baldwin's statement that two joints would be of the same strength with different thicknesses of plates, provided the rivets were of the same diameter and pitch.

Mr. OLRICK said that there was a question which he should like to test by figures, but he had not had time to go into it. It was whether the compressive strain on the section of the plate in the rivet-holes was not often too great, so as to cause a partial fracture of the iron.

Mr. ROBERTS said that the direction of the break would depend upon the section of the iron. It would not be a fair experiment to try with a single rivet. If there were another rivet and the area of the iron was larger, the chances were it would pull right across; but if the joints were of the ordinary lap, the chances were that it would pull right out.

Mr. OLRICK asked whether Mr. Roberts did not think the strains would be likely to tear the iron in the two places indicated.

Mr. ROBERTS said it was most likely it would tear a zigzag.

Mr. OLRICK said he believed that was a point not always paid sufficient attention to.

Mr. ROBERTS said, in riveted joints the engineer must be guided by the lap. He could not have a long lap.

Mr. OLRICK said, that if there was a sufficient lap, and the section was enough to resist the whole strain thrown upon it, no fracture would take place.

Mr. ROBERTS said that it was well known to all boiler-makers that they could have only a certain amount of lap. If there was too much, there would be great difficulty in making the joints tight. In trying an experiment such as Mr. Olrick had indicated, much would depend upon the direction of the grain of the iron, whether they were using the end of a plate or the edge of a plate. They would require a wider pitch on the edge than on the end, because the iron was generally weaker.

Mr. OLRICK said that it was a rule, and no doubt a very good one, to have the diameter of the rivet outside the rivet-hole. For instance, with a $\frac{3}{4}$ in. rivet there would be an overlapping

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of $2\frac{1}{4}$ in. That is to say, the distance from the centre of the rivet to the outside of the lap would be $1\frac{1}{8}$ in. Consequently, for the double lap that would give $2\frac{1}{4}$ in. If that were trimmed up and caulked, it would be perfectly tight.

Mr. SCHÖNHEYDER asked whether, when Mr. Olrick said there was not sufficient section of iron beyond the rivet, he did not mean there was not sufficient surface.

Mr. OLRICK said that he meant that the compressive strain on the edge of the plate was too great to be resisted by the iron, and therefore the iron was forced back and a fracture was commenced which could not easily be detected, but might extend and lead to disastrous explosions.

Mr. SCHÖNHEYDER said that in that case he thought "surface" ought to have been the term used, instead of "section." He should like to make some further remarks at the next meeting.

October 15*th*, 1866.

ZERAH COLBURN, PRESIDENT, IN THE CHAIR.

ON SINGLE AND DOUBLE RIVETED JOINTS.

BY THOMAS BALDWIN.

ADJOURNED DISCUSSION.

Mr. J. HENDRY said the subject of the paper was a very important one, but although it did not appear to him to contain any real practical data, yet we were much indebted to the author for bringing the matter before the Society. He would remark, that we were very much indebted to Mr. Fairbairn for the valuable data he had given us on this subject; he had been the pioneer in plate and riveted work, and had given us the fulcrum upon which to work. The experiments he made were, at the time, no doubt, correct, although some assert that they are wrong now; his own opinion is that the tables he had given were practically correct, as it must be borne in mind that different experimenters on this particular class of work very often found various results, depending entirely upon the relative qualities of plates and rivets operated upon; this was, therefore, the first point to be considered in laying down any data for riveted joints. The boiler-smith was, in many cases, as good a judge as any as to the lap of plate and distance and size of rivets, &c., when he knew what class of material he had to deal with. As regarded punched *versus* drilled holes, he was of opinion that it

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was an error to resort to drilling unless turned rivets were used; in fact, he considered it to be rather unmechanical to put ordinary rivets into drilled holes; in riveting hot rivets in drilled holes there was a great uncertainty in getting the rivets to fill the holes, one cause being that the oil, &c., used in drilling was left in the hole; then, again, there were the sharp and ragged edges, which had a tendency to cut into the heads; and, moreover, unless the ragged edges on the inside of the plates, where they come together, are dressed off, there was a fear of being unable to get a water or steam tight joint. The only point that could be advanced in favour of drilled holes was, that the plates were not so liable to be injured, and also that several plates could be drilled through at once, and so made to fit very accurately together. He was, however, quite satisfied that if punching was carefully done, and care exercised in making templates for the holes required in the plates, the one plan would be equally as good in practice as the other. With reference to the two systems of riveting—viz. by machine or manual labour—riveting could, no doubt, be done as well, if not better, by hand than by the machine, that is, if care be taken; but, unfortunately, it was not to be depended upon; work done in this manner was generally piece-work, and he had frequently noticed the rivets left red hot after having been cupped, and the consequence was that rivets so left very rarely filled the holes. Such, therefore, being the case in practice, we must resort to the machine. There were, he believed, only two kinds of machines in use—viz. steam and hydraulic; and although there may not appear to be much difference between them in the class of work done, yet he must give the preference to the hydraulic machine, as being the better, and working more steadily; and he might remark, that in machine riveting it was well to have a self-acting apparatus to keep the cup on each rivet the same length of time, and so get a uniformity throughout. In the rivets themselves one important point was often omitted, and that was to have the heads a good size and strong. He preferred the cup heads. As regarded joints being found leaking, he was afraid the fault very often arose from the rivet heads being defective, or the method adopted in caulking the joints. He had frequently seen the edges of the plates opened out by too much caulking, which was most injurious. He had seen a boiler with no caulking at all, perfectly steam-tight, except at two places; this was merely an experiment to try whether such could be done. As to cold rivets, he had had no experience with them above $\frac{7}{16}$ths in. diameter, and he was hardly prepared to say what advantage, if any, there was over a hot rivet, except that rivets made of defective iron could not be riveted cold. He

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would now direct attention to Plate A, to lay before the meeting some experiments made with a view of trying the merits of different sizes and centre distances of rivets for boilers, &c. In Fig. 1 it would be seen that the action of the punch caused the plate to bend a little, in consequence of the diameter of the hole in the die being larger than the punch; this ought, however, not to exceed $\frac{1}{16}$th of an inch. He might here remark that the durability of a punch was much increased by having the end rounded as shown. Figs. 2 and 3 show the plates as they may be put together (the curvature of the plates being drawn to an exaggerated scale), but he thought that all practical men would agree that Fig. 2 was the best way, as the ragged edges caused by the punching were on the outside, and not between the joints, as in Fig. 3. It had been found in practice that by putting the plates together as in Fig. 2 there was a better chance of getting a perfectly tight joint. Fig. 4 shows two plates as put together for the experiments. The results are given on Plate A.

Mr. Olrick said that Mr. Baldwin, in his paper, stated that the shearing force was 50,000 lb., and the tensile forces 51,000 lb. Those figures were quoted from Professor Rankine's book, but he did not believe they could be correctly applied to the case of boilers, because the iron in the plates, which varied to a very great extent, was generally of inferior quality to that of the rivets. The two areas being the same, the strength of the plate and the rivet ought theoretically to be the same; but when the great variety in the quality of iron was taken into consideration, it would be seen clearly that it was impossible to get all varieties to range under the same formula. And although there were inferior rivets used, still it was only cheap-jacks that used them. Eighteen tons to the square inch might be taken as the average strength of a boiler plate, while a good rivet would bear from 23 to 25 tons per square inch. There was another point which, according to his opinion, it was impossible to bring under a mathematical formula, that was the friction between the plates caused by the riveting. Some said—and Mr. Fairbairn was amongst them—that it was next to nothing; but other persons of almost equal eminence had found that it was very considerable, even amounting to as much as 4 or 5 tons. In some experiments which had been made to prove the friction between plates, the rivet-holes in the plates had been made eccentric, so as to allow the friction between the two plates to be ascertained before the rivet was firmly gripped by the plates which had been forced to slide on each other, until those parts of the rivet-holes which were farthest away at the commencement of the experiment were in close contact with the rivet, and the amount of strain necessary to overcome the friction of the two plates in

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contact had been as much as 4 or 5 tons before it came to the other extremity of the rivet-hole. That was 4 or 5 tons per square inch of the section of the rivet. There was also another point which was difficult to determine, namely, to what extent the plate may have been injured by punching. He next came to that part of the paper in which the author stated that a 2 in. pitch was almost universal, and that he had never been able to get a correct explanation why it should be so. In the olden time it was believed that a riveted joint was stronger than a solid plate; this seems strange to us, for by simple calculation what the strength of a joint made from $\frac{3}{8}$ plate, $\frac{3}{4}$ rivet, and having 2 in. pitch, ought to be, we find that the plate is in proportion to the joint as 1 to ·625, and the plate is in proportion to the rivet as 1 to ·588, and the area of a unit of 2 in. of plate is ·75 square inches. By the unit of a joint he meant a piece of the seam corresponding in length with the pitch of the rivets; and in such a unit of a seam made of $\frac{3}{8}$ in. plates, and a rivet of $\frac{3}{4}$ in., the section of the solid plate would be ·75 square inch; and, deducting the area of the rivet, the joint would be ·46875; the rivet would be ·4417, and consequently the strength of the joint was only ·625 of that of the solid plate. Mr. Fairbairn gives ·56, which is accounted for by additional weakness from punching. For a $\frac{1}{2}$ in. plate, with the other figures the same, that is, a diameter of rivet of $\frac{3}{4}$ in. and a pitch of 2 in., the solid plate was 1 square inch, the joint was ·625, and the $\frac{3}{4}$ rivet ·441; whereas a $\frac{7}{8}$ rivet was ·6015, and a $\frac{13}{16}$ rivet was ·5185. It was stated by Mr. Baldwin that a $\frac{3}{8}$ in. plate, riveted up in the manner described, was as strong as a $\frac{1}{2}$ in. plate. He (Mr. Olrick) did not believe that was correct; firstly, because there was more stuff in the $\frac{1}{2}$ in. plate to resist the tendency to bend the plates under strain into a straight line; and, next, the joint is always tighter or easier to make tight by caulking than the $\frac{3}{8}$ in. one; and, lastly, there is more stuff to resist internal and external corrosion. As, however, Mr. Baldwin prefers figures, he (Mr. Olrick) would also prove by figures that this statement was erroneous. In a joint made of $\frac{1}{2}$ in. plates, with 2 in. pitch and $\frac{3}{4}$ in. rivets, the area of a unit was ·625, and the rivet ·4417. He now multiplied the area of the plate with 18 tons, which is equal to 40,320 lb., and got by that multiplication 25,200 lb. For the $\frac{3}{8}$ in. plate and everything else the same—18 tons times the area of the joint, which was ·46875, gave nearly 18,900 lb. There was, consequently, 6000 lb. difference between these figures. The $\frac{3}{4}$ in. rivet was used in both cases. The area of that was ·4417, and that multiplied by 56,000 lb. (25 tons) gave 24,735 lb., which was a very close approximation to the strength of the $\frac{1}{2}$ in. plate; but Mr. Baldwin said, in his paper,

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that the $\frac{3}{8}$ in. joint was just as strong as the $\frac{1}{2}$ in. one, while these figures showed that that was not the case, the $\frac{3}{8}$ in. plate being nearly 6000 lb. weaker than the other. He assumed the best workmanship and the best rivets, which would stand a tensile strain of 25 tons to the square inch. Respecting the next point to which he should refer, he should have to differ from Mr. Baldwin and Mr. Pendred. Mr. Baldwin said that the use of a $\frac{1}{2}$ in. plate would make the boiler 25 per cent. dearer; and Mr. Pendred corrected that by saying 33 per cent. In his (Mr. Olrick's) opinion, they were far in excess. It was perfectly correct that adding $\frac{1}{8}$ in. to $\frac{3}{8}$ in. would be an addition of one-third, or 33 per cent., to the thickness; but both Mr. Baldwin and Mr. Pendred had forgotten that that was only a difference in the material, and unless the boilers were sold by the ton it would make very little difference in the cost.

Mr. Pendred said he did not wish it to be understood that he endorsed Mr. Baldwin's opinion of the cost at all. He gave no opinion; he merely corrected Mr. Baldwin's statement.

Mr. Olrick said that instead of Mr. Pendred making Mr. Baldwin's view better, he made it worse.

Mr. Pendred said he merely corrected it; he gave no opinion at all himself.

Mr. Olrick said he now came to formula (4), and applying same, he got by calculation the pitch equal to $\frac{\cdot 44 \times 50{,}000}{\cdot 375 \times 51{,}000} + \cdot 75$, which was equal to 1·9 in. pitch, and that would be in practice 2 in. pitch. This showed that, according to Mr. Baldwin's own formula, he (Mr. Olrick) got a pitch which Mr. Baldwin to some extent condemned. If we referred to formula (6), we would get 1·928 in. pitch; and as the rivet was generally larger than exactly $\frac{3}{4}$ in.—or at any rate the hole was—the rivet would be increased in diameter by riveting by about $\frac{1}{16}$th of an inch. We would, consequently, get a pitch of about 2 in. Mr. Baldwin next referred to Mr. Fairbairn's Table, giving thickness of plates, diameter of rivets, and the pitch of the rivets; and applying these data, he finds by his equation (5) the values of n in Table I., column 5; but several of these values were incorrect, as Mr. Baldwin had not checked Mr. Fairbairn's Table before he used same, which would have prevented his being led into these inaccuracies. He (Mr. Olrick) now produced Mr. Fairbairn's Table as corrected by him;

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THE CORRECTED FAIRBAIRN TABLE.

Plate t.	Rivet d.	Pitch p.	a.	n by equation (5).
$\frac{13}{16}$	·375 } 2	1·25 } 6	·11044	33670
$\frac{1}{4}$	·500	1·50	·19635	39270
$\frac{5}{16}$	·625	1·5625 } 5	·3068	52360
$\frac{3}{8}$	·75	1·875	·4417	52349
$\frac{3}{8}$	·75	2·0	·4417	46933
$\frac{1}{3}$	·75 } 1·5	2·0 } 4	·4417	35336
$\frac{5}{8}$	·0375	2·5	·6903	35346
$\frac{3}{4}$	1·125	3·0	·9940	35343

If this Table is compared with the original Fairbairn Table, several important inaccuracies will be found, which have led Mr. Baldwin into wrong deductions. It must here be remembered that the figures 2, 1·5, 6, 5, 4 in the preceding Table are multipliers which must be multiplied with the thickness of the plate to get the diameter and pitch of the rivets. Taking as an example the first line for $\frac{3}{8}$ in. plate, we get the diameter of the rivet by multiplying $\frac{3}{8}$ by 2, which gives $\frac{3}{4}$, or ·75 in. Again, multiplying $\frac{3}{8}$ by 5 we get 1·875 in. as the pitch, and not 1·75, as stated in Fairbairn's Table. Now, applying this corrected figure in rule (5) we get

$$n=\frac{22085}{(1{\cdot}875-{\cdot}75)\,{\cdot}375}=\frac{22085}{{\cdot}421875}=52349\text{ lb.}$$

instead of 58,893 lb., as given in Mr. Baldwin's column of Fairbairn's Table. Applying the same rule to $\frac{1}{2}$ in. plates, we get 35,336 lb. instead of 43,666 lb. Referring to the formula (A), the mean pitch for $\frac{1}{2}$ in. plates would be 1·63 in., which he (Mr. Olrick) did not consider a good proportion; whereas, if the rivet was increased by $\frac{1}{16}$th of an inch, the pitch would be $1\frac{7}{8}$ in., and with $\frac{7}{8}$ in. rivets the pitch would be 2 in., which was a far better proportion.

MR. ROBERTS'S TABLE.

t.	d.	p.	Area of Joint.	Area of Rivet.
$\frac{1}{4}$	$\frac{1}{2}$	1·25	·1875	·1963
$\frac{3}{8}$	$\frac{3}{4}$	1·875	·4218	·4417
$\frac{7}{16}$	$\frac{7}{8}$	2·1875	·5742	·6013
$\frac{1}{2}$	1	2·5	·75	·7854

He had calculated the preceding Table from the formula given by Mr. Roberts, who said that he took the thickness of the plate and multiplied by 2 to get the diameter of the rivet; then, to get the pitch, he multiplied again the diameter of the rivet by $2\frac{1}{2}$.

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With $\frac{1}{4}$ in. plates, rivets of $\frac{1}{2}$ in. diameters, and $1\frac{1}{4}$ in. pitch, the area of the joint would be ·1875. The area of the rivet would be, as shown in the Table, ·1963. For $\frac{3}{4}$ in. Mr. Roberts used a pitch of $1\frac{7}{8}$ in. There he got the rivet ·44, and the joint ·42. For $\frac{7}{8}$ in. rivets he got also a larger area of rivet than of joints; and so, although Mr. Roberts had no doubt had a great many years' experience, yet it seemed to him (Mr. Olrick) that, when tested by the test he had applied, which was to multiply the area of the joint by the 18 tons, and the area of the rivet by 25 tons, Mr. Roberts's rivets would be far stronger than his joints—that is to say, the iron between the rivets.

The résumé of his remarks was the following:

Mr. Baldwin had started from wrong data, and, consequently, he arrived at wrong results; and as he (Mr. Olrick) had taken different data, he came to different and, as he believed, more correct results. He believed that, all things considered, the 2 in. pitch was not so bad as it was represented by Mr. Baldwin. It might be too much in many instances; but they must, of course, be guided very much according to circumstances. And, again, it might be too small in others; but, if they increased the pitch too much, they would get a defective and leaky boiler, on account of too great a distance between the rivets. There was no doubt that unnecessary deviation from a standard pitch was objectionable, and should only be resorted to where it was actually necessary; but the particular circumstances under which a boiler was to work must, of course, be considered; and a mathematical formula could therefore not be made to apply in all instances unless a co-efficient for each particular case were introduced, and that would no doubt be more trouble than good. A boiler made to carry 5 lb. pressure, and a boiler made to carry 100 lb., were boilers working under quite different circumstances, and the practical engineer or boiler-maker would have to choose his pitch according to the varying circumstances. In reports of boiler explosions he had never found any particular complaints against the 2 in. pitch. At the last meeting, some remarks were made by Mr. Cargill about rivets with skewed heads; but really that was only bad workmanship; and when they came to discuss a question of this sort he did not think it was worth while to bring all the cases of bad workmanship into notice, because, if they were taken into consideration, they would get an amount of rules that would really be of no practical value. Mr. Cargill also made some remarks about filling up holes, to the effect that a rivet was better if the hole was not quite filled up than when it was. He (Mr. Olrick) must respectfully decline to accede to that. He could not see any practical reason for it, and he should always be inclined to have the holes properly filled up. Mr. Roberts corroborated that view in several distinct instances. When the

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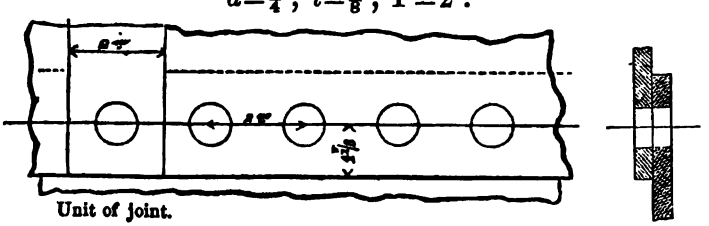
holes were not properly filled up, and the hydraulic test was applied to the boiler, there was no doubt the plates might actually be shifted out of their original place; but he (Mr. Olrick) was afraid there would then be no possibility to get that boiler tight again after the plates had been shifting about in this manner. Mr. Roberts stated that from some experiments of his he found that the holes were seldom properly filled up when the length of the rivets were three times their diameter. Thus, in the case of $\frac{3}{4}$ in. rivets, the length would be $2\frac{1}{4}$ in.; but, of course, such a length between the head and the snap of the rivet would seldom or never be found in boilers. Mr. Schönheyder made some remarks about "section" and "surface," and he said that he (Mr. Olrick) ought to have said "surface," and not "section." When the strain was excessive on the rivets, no doubt there was a tendency in the bottom half of the rivet to crush the edge of the plate; and if it commenced to crush it, rents in different directions were sure to follow. He admitted that "section" was not a well-chosen expression, but it was, at any rate, better than "surface;" for what had they to consider in the case he had pointed out? They had to consider, not the surface of one-half of the rivet-hole, which would be expressed by $\frac{d \pi t}{2}$, but they had to consider only the projected section, which would be expressed by $d t$; so, consequently, if he was wrong in expressing himself, at any rate the name he gave it corresponded with the mathematical expression. The word "surface" did not apply, because they had nothing to do with the surface.

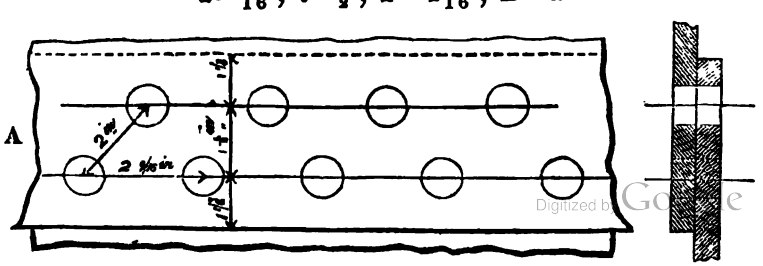
ORDINARY SINGLE-RIVETED JOINT.

$d=\frac{3}{4}''$, $t=\frac{3}{8}''$, $P=2''$.



DOUBLE-RIVETED JOINTS.

$d=\frac{13}{16}''$, $t=\frac{1}{2}''$, $P=2\frac{9}{16}''$, $D=2''$.



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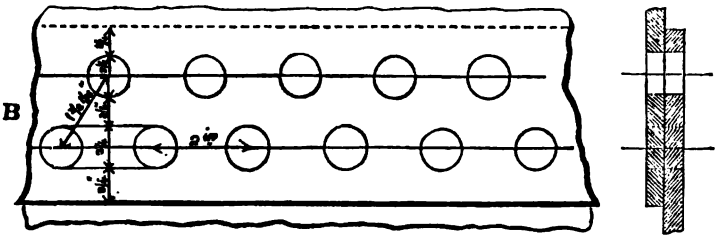
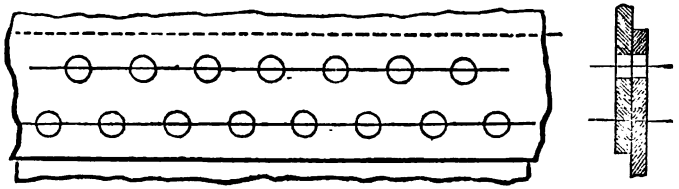
$d=\frac{3}{4}''$, $t=\frac{3}{8}''$, $P=2^{\text{ins.}}''$, $D=1\frac{3}{4}\frac{1}{16}''$.

B



$d=\frac{1}{2}''$, $t=\frac{5}{16}''$, $P=1\frac{3}{8}''$, $D=1\frac{3}{8}''$.

C



He now came to double-riveted joints. He had exhibited a sketch of a joint, A, which was given to him by Mr. Alexander. It had a pitch of $2\frac{9}{16}$ths. The diameter of the rivet was $\frac{11}{16}$ths, and the thickness of the plate $\frac{1}{2}$ an inch. The distance, D, was 2 in., and the distance from the centre of the rivet-row to the edge of the plate was $1\frac{1}{8}$th, and from centre to centre of the rivet-rows it was $1\frac{1}{2}$ in. Joint B was a double-riveted joint which he had used himself. The diameter of the rivets was $\frac{3}{4}$ in.; thickness of the plate, $\frac{3}{8}$ths; pitch, 2 in.; and the distance, D, measured diagonally, $1\frac{3}{4}$ in. They would find that the distance from the rivets to the outside of the plate was equal to the diameter of the rivet. The total distance from edge of plate to edge of plate was five times $\frac{3}{4}$ of an inch, which gave $3\frac{3}{4}$ in. Joint C was proposed for some locomotives now being made. The diameter of the rivets was only $\frac{1}{2}$ an inch; thickness of plates, $\frac{5}{16}$ths of an inch; pitch, $1\frac{3}{16}$ths in.; and the distance, measured diagonally, was also $1\frac{3}{16}$ths in. It was, consequently, an entirely isosceles triangle. The same objections which he (Mr. Olrick) had mentioned relating to single-riveted joints did equally apply to double-riveted joints, and he should therefore abstain from repeating them. There was one point which he could not pass over without calling attention to. The author said: "In circular steam-boilers with two flues the strain on the riveted joints is very variable," &c. That was a point which he did not consider quite correct, as he hoped to prove. It ought to be a strain of 2 to 1, and not 3 to 1. He had put it in figures, as the members would then be better able to understand his assertion:

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Let d = diameter of boiler in inches,
l = length of do. in inches,
P = pressure in lb. per square inch,
$\pi = 3{\cdot}1416$;

Then $d\,l\,\mathrm{P}$ = total strain tending to tear the boiler asunder *longitudinally;*

And $2\,l\,t$ = the area of plate in the shell resisting and balancing the above strain.

From this we get:

(1) $\frac{d\,l\,\mathrm{P}}{2\,l\,t} = \frac{d\,\mathrm{P}}{2\,t}$, which gives us the thickness of the boiler-plate, when rupture is about to take place, under a steam pressure, P. This applies, however, only to a strain tending to tear the boiler *longitudinally.*

Next $d^2\frac{\pi}{4}\mathrm{P}$ = total strain tending to tear the boiler asunder *transversely;*

and $d\,\pi\,t$ = the area of plate in the shell resisting and balancing the above strain (on the point of fracture).

From this we get:

(2) $\frac{d^2\frac{\pi}{4}\mathrm{P}}{d\,\pi\,t} = \frac{d\,\mathrm{P}}{4\,t}$, which gives us the thickness of the boiler plate, when rupture is about to take place, under a steam pressure, P. This applies, however, only to a strain tending to tear the boiler *transversely;* and when we compare this formula with the above, we find that the boiler is of double the strength transversely compared with the longitudinal strength.

Mr. Baldwin said, that Mr. Olrick had left out the flues of the boiler. He (Mr. Baldwin) had taken the case of a two-flued boiler, and Mr. Olrick had not taken out the area of the flues in calculating the strain upon the end of the boiler.

Mr. Pendred said, Mr. Olrick had left out the substance of the flue.

Mr. Olrick said, that when such an exception was made it ought to have been explained in the paper.

Mr. Baldwin said, two flues were mentioned.

Mr. Olrick said, that although the flues were stays, still there were many boilers without flues; and therefore it did not remove the fact that longitudinally the boilers were only half as strong as transversely. At the end of the paper, Mr. Baldwin remarked that in Lancashire and Yorkshire it was usual to use a 2 in. pitch and $\frac{3}{4}$ in. rivets, whether the plates were $\frac{3}{8}$ths, $\frac{7}{16}$ths, or $\frac{1}{2}$ an inch, and that that practice could not be too much con-

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demned. He was sorry to say that it seemed to him that the very remarks proved that it was better to maintain what he condemned, because it was preferable to have a standard pitch as was used by those men who had to do with hundreds and, he might say, thousands of boilers. He believed that practical experience was far better than even the experiments made by Mr. Fairbairn and other eminent men. He would now make two or three remarks in respect to the Norwich explosion. He had seen a very explicit description of the boiler, and found it was a double-riveted boiler; but when he came to calculate what that boiler ought to have stood for an ordinary working pressure, which was 100 lb. to the square inch, he found that not more than 85 lb. ought to have been put upon it regularly; and he also found that the hydraulic test which was applied was as much as 240 lb. to the square inch; consequently, nearly three times the working pressure. That was far above what ought to be applied. For two days there was a constant pressure of 200 lb. on it. In many firms it was usual to use the hydraulic test to double the working pressure, but he believed that if, instead of using cold water, they were to use the water boiling hot, and then test the boiler 50 per cent. more than the maximum working pressure, that would be far better, and, using the hot water, more equal to the circumstances under which the boiler would work in general. Mr. Hendry had gone fully into the question of punched *versus* drilled holes. He (Mr. Olrick) would merely say, in reference to that, that when the holes were punched flaws in the plate could be detected, whereas if the holes were drilled a flaw could not be detected—on the contrary, the drilling would conceal it. No doubt steam riveting for straight seams was preferable to hand-riveting, because it did not interfere with the crystallisation of the iron of the rivet. As to not knocking down the end of the rivet till it was perfectly cool, he did not believe in that. He believed that one reason, though one often neglected, why makers could not make boilers tight was that they never caulked them inside as well as outside. No doubt the whole question of boiler-making required much more light than they at present possessed; but, although they might differ from Mr. Baldwin, they were all much obliged to him for bringing such an important question before them to be fairly discussed.

Mr. Roberts said that, with regard to the formula he gave at the last meeting, he certainly did not lay any great claim to originality. It appeared a very simple matter, and he was surprised at Mr. Olrick finding fault with the slight extra strength in the area of the rivet. It worked out very closely, and he did not think there was much to grumble at. The difference was very little. In a $\frac{1}{4}$ in. plate one would be ·1875, and the other ·196; and

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it was no good to give elaborate formula to the workman; a plain rule was the most serviceable to him. He (Mr. Roberts) agreed with Mr. Olrick that practical experience was better than experiments, and certainly it was very much better than theory. Theorising for six months would never make a boiler. According to his promise, he had made a few experiments since the last meeting. [The experimental specimens were exhibited.] In the first place, there was a piece of plate (Fig. 1, Plate B) with a single rivet in it, to ascertain what the shearing strain would be. Mr. Baldwin, upon the authority of Mr. Fairbairn and Professor Rankine, gave it at 50,000 lb. per inch. The rivet exhibited sheared off at 9⅞ tons. That was exactly 50,158 lb. to the inch.

The PRESIDENT asked whether that was any particular mark of rivet iron.

Mr. ROBERTS replied that it was the Thames Iron Works best brand. He next riveted two pieces of plate together with punched holes. On putting this into the testing-machine, it broke across the rivet-holes at 17½ tons (Fig. 2), which was equal to 46,806 lb. per square inch of section. That was only ordinary plate. He then took one piece of the same iron, and broke it without any holes in it (Fig. 3), and found that it bore a strain of 26⅞ tons. That was, as nearly as possible, about 40,133 lb. to the square inch.

The PRESIDENT asked how Mr. Roberts got the gripe of it.

Mr. ROBERTS said he did it by the ordinary gripe—simply wedges (see Fig. 7). The strain in this case was nearly 40,133 lb. per inch. That was about 11½ per cent. less than the section with the punched holes bore, and he had no doubt whatever that 11½ per cent. was due to the gripe of the rivet. He drilled three holes in the same manner, with the same pitch, namely, his own. That was 2½ diameters, and that was tested in precisely the same way. That bore (Fig. 4) 54,495 lb. to the square inch of section, which was very considerably indeed above the punched plates; and upon taking the piece that broke in the same manner as the first piece, and testing it again, he got 28⅜ tons (Fig. 5); so that the result is, that the one plate broke at 40,133 lb. per square inch, the other at 42,361 lb.

The PRESIDENT said, he supposed Mr. Roberts did not consider this iron better than the other on that account.

Mr. ROBERTS said, it was the same plate precisely, only one was drilled and the other punched.

The PRESIDENT said, the specimen had all the appearance of an iron that might stand a greater tensile strain; there was no stretch in it.

Mr. ROBERTS said, they were all got from the same plate;

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now, by adding 46,806 lb., the breaking strain of the punched plates, to 54,495 lb., the breaking strain of the drilled plates, the mean of those two results would give 50,650 lb. as the breaking strain of the plate, against 50,158 lb. for the rivet; so they might come to the conclusion they were pretty nearly at the correct pitch. Then, to go a little further, he took two more pieces of the same plate, and riveted them with two rivets only (Fig. 6). One broke across the two rivet-holes, and that broke from a little lower strain. Through having only two rivets, the plates were much more bent than when there were three rivets. This specimen with two rivets broke at 17 tons, giving only 45,668 lb.; so that although the drilled holes came considerably over the 50,000 lb., the shearing strain of the rivets—just as much over as the punched holes came under it—still it gave a mean between the two. The metal used was ordinary Staffordshire iron. The experiments spoke for themselves. With reference to Mr. Pendred's remarks, he had brought specimens (Fig. 8) to show the perfect filling of the holes by the rivets. Three had punched holes, *a*, *b*, *c*, the remainder were produced by the same drill, and all the rivets were of the same size. They would observe that none of the long rivets filled up the holes, except for a short distance near the point. The two end rivets closed the holes up very nicely, or very fairly. In one case, *c*, three plates were punched, and the rivets did not close the holes up quite so well, although the rivets were put in as tight as they would go. Since the above discussion, I have had an opportunity of examining some machine riveting, and find that so far from its having the advantage claimed for it by Mr. Cargill, viz. keeping the axis of the rivet *exactly* opposite the head, not 5 per cent. were in that condition; and, taking this as a fair sample, consider it wholly unfit for high-pressure boiler-work, or even for boilers intended to work at pressure of 50 lb. per inch.

Mr. Cargill said that Mr. Olrick had taken exceptions to some remarks made by him (Mr. Cargill) at the last meeting as to machine and hand riveting. Mr. Olrick said that they had no right to take the circumstance of bad workmanship into consideration in deducing rules. That was correct; but in claiming advantage for machine riveting he (Mr. Cargill) merely claimed those advantages which belonged to the use of all machinery compared with hand labour. As a rule, machine labour did not come up to what could be done by the very best hand labour; but what was lost in one way was gained in another. The value of a machine was that it would do the work thoroughly and uniformly, while men required constant supervision. He had said at the last meeting that the French engineers had tried some experiments with rivets in which the holes were not quite

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filled up. Mr. Olrick, in remarking upon Mr. Baldwin's paper, had, by a different process of reasoning from himself (Mr. Cargill), arrived at the same result. It appeared to him that in the consideration of the joints there had been an element neglected; that was the bearing surface of the plate upon the rivet. It seemed to be considered that there was nothing more to do but to obtain a sufficient area of rivets, and the thing was done. Where joints were designed in that way, and subjected to a breaking strain, the plates would hold, and the rivets go. It was not so much the area of the rivet that they would have to take into consideration in a joint, but its efficiency. That was the limit of the power it exercised upon the plate. It could not be assumed solely that the plates were to cut the rivets, or the rivet cut the plate; and, therefore, he should design the rivets in a different manner to that given by the formula in the paper by Mr. Baldwin. He should take its efficiency as the crushing weight of the plate bearing upon it. In designing any structure they must design for the weakest part, and not for the strongest. If they designed for the strongest part of the joint, there was so much waste, because the weaker part would not bear the strain. Although the result of Mr. Fairbairn's experiments bore out pretty well the rule that the area of the rivet should be proportionate to the area of the nett section of the plate, yet he only used one wrapper on the top. That was bad policy. It was remarked at the last meeting that a lap joint was stronger than a butt joint. He thought it was very probable that a lap joint would be stronger than a butt joint with only one wrapper. The reason why a lap joint was stronger than a butt joint with one wrapper was that the section of the whole shell was never less anywhere than the section of the thinnest plate. At the joint itself, in a butt joint, the section was absolutely nothing at all, and they had to make up the loss of section by a wrapper. In the other case, the joint was made part and parcel of the whole boiler. That was the reason why the lap joint would be stronger than a butt joint with one wrapper. Mr. Roberts had said that it was no use giving formulæ to boiler-makers. That was very true, but the result of the formulæ might be given, which would be sufficient.

Mr. Roberts: If a man understood it.

Mr. Cargill said, the men would understand the one just as well as the other.

Mr. Roberts said his experience was otherwise.

Mr. Cargill said, that if a foreman did not know how to use the results of a formula, the sooner they knew it the better. He did not himself see that there was any difficulty in applying a formula practically, so that it could be understood by men in the position of foremen.

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Mr. JENSEN said, it struck him that Mr. Olrick had made a mistake in comparing the strength of the rivets with that of the joints, because he had overlooked that the shearing strength was a different thing from the tensile strength. He put the tensile strength of the rivet down as 25 tons, but the shearing strength would be only $\frac{5}{6}$ths of that. Applying that to all the different results that Mr. Olrick had worked out, they would be very materially altered.

The PRESIDENT asked if Mr. Jensen would give some authority for that, because it was a very important point. Mr. Jensen must be quite aware that many people believed the tensile strain to be the same as the shearing strain, and there were several experiments which went very strongly to prove that it was the same.

Mr. JENSEN said he thought it would be found that Mr. Rankine said the shearing strain was only $\frac{5}{6}$ths of the tensile.

Mr. OLRICK said that Mr. Fairbairn stated in his book that it was equal.

The PRESIDENT said, that in a very large hydraulic shearing-press, made by Tangye Brothers, of Birmingham, which was intended to work up to some 200 or 300 tons, it was found, in cutting railway tires of 10 square inches, that the shearing strain was almost exactly equal to the known tensile strain of the bar.

Mr. JENSEN said, he went by what Professor Rankine had laid down in his standard works, and according to that there would be a very great difference in the results. The formula and practice of Mr. Roberts seemed to point the same way.

Mr. DAVY said, he understood that in the experiments that had been made the joints had been put together and the strain had been put upon them without any caulking at all. He believed that caulking a joint seriously affected it, and in making experiments for the purpose of preparing data for calculating strains in order to come to correct results the joints should be caulked. Mr. Olrick alluded to the resistance caused by mere friction of the surfaces of riveted plates as 4 or 5 tons. Perhaps he took that from Mr. Clark's work, in which he gave from 4 to 8 tons for rivets up to 3 in. long. It was evident that in caulking a joint, especially if a considerable lap is given, the plate would be buckled, and consequently that would destroy the frictional resistance of the plates to some extent, and if it be caulked both inside and out the result would be greater; but caulking with a double-riveted joint could not so seriously affect it, as the area of the plates between the two rows of rivets could not be buckled. He should like to know whether any gentleman had experimented in order to determine the difference between a joint which was caulked and one which was not. Mr. Hendry had drawn a joint to represent the buckling of the plate conse-

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quent upon indirect strain, but that was not exactly the case in which the strain was put upon the joint of a boiler. When the joints were put together in the boiler, the line of the true circle could not generally be found to cross the rivet in the centre, if the plates were actually segments of a circle; but in putting the plates together one was buckled out a little, and the other in a little, so that the true circle would pass nearly in a direct line with the plates, and probably that would have a good effect.

Mr. OLRICK read a communication from Mr. Alexander: "We are all aware that the 2 in. pitch is by no means invariable, but is altered considerably to suit different thicknesses of plates and diameters of rivets. He did not doubt that the table of pitches given in Mr. Baldwin's second table, if carried out in practice, would give very good results; but the relation of the compressed surface of the plate against the semicircumference of the rivets to the other dimensions was, he thought, sometimes important, and does not appear to be considered in the paper, so far as he had seen it. If this surface was too small and inadequate to resist the strain, it began to *crush*, leading to a partial fracture of the plate at the rivet-holes, and hence to the rupture of the remainder of the plate in *detail* by tearing. The resistance to crushing is measured by the diameter of the rivet × the thickness of plate; and if the relation of this surface is perfectly adjusted to the section of plate between rivet-holes, then $(P-d)\,t=d\,t\,c$:—c being a co-efficient to be determined, and ought to be constant. Then $C=\frac{P-d}{d}$; and if we assume that $\frac{3}{4}$ in. rivets are sufficient for a pitch of 2 in., then $\frac{P-d}{d}=\frac{2\text{ in.}-\frac{3}{4}}{\frac{3}{4}}=1{\cdot}66=C$. As in the above fraction the consequence of increasing d in reference to P is to reduce the value of c, and this increase also reduces the pressure on the compressed surface per unit of area, a diminution of the co-efficient implies a stronger joint, *in as far as there is risk of rupture from the crushing of the material*, and it is evident that the *closely pitched* joints are the strongest in this respect. Of course, this is not the most important consideration, but it is one which he thought ought not to be neglected in determining the exact proportion of an important joint. In Mr. Baldwin's Table this co-efficient does not remain constant; hence the joints are not equally good in this respect. Take the $\frac{5}{8}$ in. plate, with 1 in. rivets and 2·2566 pitch, then $\frac{2{\cdot}2566-1}{1}=1{\cdot}2566$; as there is less risk in this joint of tearing the seam from crushing than in the case previously supposed of a $\frac{3}{8}$ plate, with 2 in. pitch and $\frac{3}{4}$ in. rivets. If we take the case of the three plates, each $\frac{1}{2}$ in. thick, with $\frac{3}{4}$, $\frac{13}{16}$, and $\frac{7}{8}$ rivets, sup-

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posed by Mr. Baldwin, the pitches given in Table II. being 1·6334, 1·8496, and 2·0776 respectively, the co-efficients are 1·178, 1·276, and 1·375, as the largest pitch has a crushing strain on the material about 16 per cent. greater than the smallest pitch. This does not, of course, subvert the conclusion that the larger pitch forms the strongest joint; but it prevents us from assuming that the strength of the two joints will be exactly as the area of metal in tension, or as (1·6334 − ·7500) = ·8834 : (2·0776 − ·8750) = 1·2026 in the two cases; *i.e.* that the larger pitched joints will be about 36 per cent. stronger than the other; for it is more apt to be destroyed in detail, as he explained, by the commencement of a crushing action round the rivet. The joint, he thought, required still more careful attention when thin steel plates were in question."

The Hon. Sec. read the following letters from W. Fairbairn, Esq., and J. Pinchbeck, Esq.:

DEAR SIR,—I am personally obliged to Mr. Baldwin for the attention he has bestowed upon the question of riveted joints. I did not expect that my experimental researches would stand a perfectly uniform mathematical test, as my table of diameters, pitch of rivets, &c., was deduced from the experiments having reference to practical results. I am, however, glad to find, from Mr. Baldwin's investigations, that the proportions given in my paper for the joints of plates varying from $\frac{5}{16}$ to $\frac{1}{2}$ in. in thickness approximate very closely to Mr. Baldwin's formula.

In hopes of the subject being well ventilated at the forthcoming discussion,

I am, dear Sir, yours faithfully,

W. FAIRBAIRN.

A. Williams, Esq.

Mr. PINCHBECK stated he could not agree with the writer of the paper, because he proceeded on the assumption that the strength of boiler plates and rivets were nearly equal, if their section was the same. We all know that this is far from being the fact, and that the plate is seriously injured in the process of punching. Mathematical formula is all very well, but if the starting-point is a fallacy it becomes a mockery and a snare. And this is the case here, for the influence of the quality of the iron employed would be greater upon the pitch of the rivets in a boiler than the thickness of the plates themselves. Presuming as a general rule that few boilers are made less than $\frac{3}{8}$ thick, or more than $\frac{1}{2}$, the distances given in the table show a difference of a fraction of an inch; it is, therefore, useless to trouble practical men with formula if the point of departure, viz. the

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quality of the iron, varies more than does the result of such formula. Again, boiler-makers who have self-acting punching machines, and punch two or three holes at a time, would find it extremely inconvenient to alter the pitch of the punches by a fraction of an inch. In practice the complication introduced by having three pitches for three thicknesses of plates would be found extremely annoying to the workman. If the rivet-holes in boilers could be placed slightly out of the straight line to the extent of even one-half a diameter, he thought much strength would be gained at little extra trouble. All knew the effect produced if a series of nails were driven into a piece of planking in a straight line, but if the nails were driven alternately in two lines comparatively little injury was done to the timber. In a lesser degree the same thing takes place in the punching of plates. Nothing can be more injurious to boiler-work than much caulking; when this is necessary, we may be certain the faces of the plates were not properly drawn together by the rivets, as should be the case. The effect of much caulking is to loosen the rivets, and to render it difficult to get them tight afterwards. If the edges of the plates are planed, very little caulking is necessary to make the joints perfectly tight. A great deal might be said on this subject. He had seen workmen for days caulking a boiler, and the more they caulked the worse it leaked. He thought, therefore, too much care could not be taken to reduce the amount of hammering at the joints when the boiler had been riveted up. He wished, lastly, to observe that he thought it desirable that boiler-makers should anneal the plates before beginning to punch them, a practice he had himself followed for years. There could be no doubt the effect of the chill upon the iron during the process of rolling it was to render it brittle. The annealing to a certain extent restored its original ductability. Another advantage was that imperfections in the plates themselves were more easily detected when they were red hot than when cold. Flaws by this means were discovered which would otherwise pass unnoticed, or only seen when the expense of punching and bending had been incurred.

Mr. Olrick said, in answer to Mr. Davy, that the data as to the amount of friction between two plates riveted together, he had obtained from the manager of the works he had referred to, and not from Mr. Clark.

Mr. Batley said that the first speaker at this meeting gave relative dimensions for the diameter of the punch and die. Those dimensions might be applicable to certain thickness of plate, as for instance $\frac{5}{16}$ths or $\frac{3}{8}$ths; but if the same clearance was used for $\frac{1}{2}$ in. or $\frac{5}{8}$ths in., the injury done to the plate in the process of punching would be serious. He had seen a die used experimentally with a hole the same size as the

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punch, and the plate actually split in punching. His own experience was that the hole in the die must vary considerably, according to the thickness of the plate. With regard to filling the holes with the rivets, there was certainly much difficulty in so doing where the length of the rivet was considerable as compared with the diameter. But he thought more depended upon the mode of heating the rivet than upon its length. In almost all cases of hand riveting the rivet was heated in a portable forge through a plate which protected the head from the action of the fire to a considerable extent: they would frequently find the point at welding heat when the head was nearly black. In his own experience, both in hand and machine riveting, he found that a small furnace was far preferable to a portable forge. A furnace might be made perfectly portable, and in it the rivet would be heated all over, and, consequently, it would fill the hole under the head as well as under the point. He had seen machine riveting in which it was necessary to employ acids to detect the division between the rivet and the plate, no line being shown on the planed surface, where the rivet passed through the plate. Mr. Hendry mentioned two classes of machine-riveting; there were, however, three—viz. the steam riveting, hydraulic riveting, and also the mechanical riveter, in which the pressure was obtained by a cam or an eccentric. In the direct steam action the ram might be withdrawn before the rivet was fairly squeezed home. When the riveting was done by a cam the plates would be brought fairly together, and the rivets closed and partially cooled before the ram left the rivet. He much preferred that mode to either steam or hydraulic riveting. He always used rivets the heads of which were at least double the diameter of the body, so that they would get a good gripe over all the edges of the rivet-holes. With regard to the shearing and tensile strains, there certainly was a decidedly greater strength tensionally than to resist shearing, but he had not gone sufficiently into that subject to say whether the difference was produced by the irregularity and roughness of the edge of the hole, which tended to cut into the rivet, or whether it was simply the natural property of the iron. He had always found the shearing strength less than the tensile.

Mr. Perry F. Nursey said that the object aimed at, both in the paper and in the discussion, was to determine how best to produce a thoroughly good joint, and the best possible method of effecting it. That point was of the highest importance in all riveted joints, especially those of steam-boilers, where badly made joints often led to corrosion, thus weakening the boiler-plate, and frequently resulting in a fatal accident. The defects arising from riveted lap-joints were, however, capable of remedy by departing from the course ordinarily followed in the con-

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struction of the boiler. The principle adopted by the London and North-Western Railway Company was to form each length of the barrel of the locomotive boiler out of a single plate bent round into a complete circle, so as to have only one longitudinal joint instead of two. That joint was turned to the upper side of the barrel, so as to be in the steam space above the water-line; and thus the difficulty of corrosion along the longitudinal joint was to a great extent overcome. But the locomotive engineer of the Midland Railway, some years since, adopted a still better method of construction, which consisted in having the plates rolled with thickened edges. By that plan it was found that the injury previously experienced from corrosion was entirely obviated. In carrying out that plan the ordinary thickness of $\frac{7}{16}$ in. was preserved in the body of the plate, the edges being thickened to $\frac{5}{8}$ in., with a long gradual taper in the thickness about 4 in. long. Where plates were flanged to do away with an angle-iron, the taper ensured a gradual springing of the plate, distributed over all that length, instead of the sudden bending concentrated at one point. The transverse circular joints were also formed with a similar section of thick-edge plate. By that mode of construction additional strength was gained, as the increased thickness of the plates between the rivet-holes compensated for the loss of section by the holes. As an instance of the practical working of this system, he (Mr. Nursey) would mention that one of the Midland locomotives worked for eleven years and a half with an ordinary boiler, which at the end of that time was extensively grooved and pitted. A new boiler with thick-edged plates was then substituted, and the engine had worked for nearly seven years, when an examination showed that the plates were free from grooving, although pitting had set in. But if that method prevented grooving, it did not remove the injurious strains which resulted wherever a lap-joint was used. An improvement upon the last plan was to weld the joints, thus rendering the barrel truly cylindrical throughout. That was now done on the Midland Railway, where the longitudinal joints of the three rings forming the boiler-barrel were welded and united to each other with flush butt points. The meeting ends of each ring were turned in a lathe and united by covering strips formed of welded flush rings shrunk on over the joints and double riveted. Strengthening hoops were also shrunk on each of the centre plates; they crossed the longitudinal joints, and were secured in place by a few rivets. The soundness of that system was apparent from the fact that a Midland engine with a boiler so constructed was started in 1847—nineteen years since—and the original boiler-plates still stood, never requiring repairs, nor showing any signs of grooving. As regarded the strength of welded

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as compared with that of riveted joints, it would seem that there was a gain on the side of the former. A comparison of the results of some experiments with welded joints with those made with riveted joints, and just given by Mr. Kennedy, would place the matter in a clearer light. Mr. W. Kirtley recently told the Institution of Mechanical Engineers that strips of plate cut from some of the Midland welded boilers to form the opening for the steam dome were tested with the following results: Three sets of strips were tested of 1 in., 1⅜ in., and 1½ in. plate respectively, each piece being 7½ in. in length and cut transversely to the weld, which was in the centre of each piece. Twenty-three strips were tested in all, and of these eleven broke in the weld and twelve in the solid. A very fair average breaking strength of 20·6 tons per square inch was obtained. Eleven strips of the same plates unwelded were also tested, and gave an average breaking strain of 23·6 tons. The general result, therefore, was that more than half of the welded strips broke in the solid and not in the weld, and that the average breaking strength of the twenty-three welded plates was within one-eighth of the full strength of the eleven unwelded plates. Mr. Kennedy had stated the results of three experiments with riveted joints to be 20—15 and 20 tons per square inch respectively. That at once clearly showed a per-centage in favour of the welded joints. In fact, the practice of welding instead of riveting the joints of locomotive boilers had worked so well on the Midland line, that he (Mr. Nursey) believed that company had nineteen welded boilers in use, and were constructing all their new boilers on the same principle, employing special machinery for flanging, bending, and welding.

Mr. Baldwin, in reply to the discussion, said that if he were to answer all that had been said, he should have to talk for the rest of the week. He would confine himself entirely to what bore upon his paper. The data from which he constructed that paper were chiefly the experiments of Mr. Fairbairn, made upon riveted joints, not upon plates unriveted; and consequently everything that had been stated about the tension of the rivet acting upon the plate fell to his lot, so far as the resistance to shearing was concerned. A great deal had been said about the shearing force and the tensile strain not being equal. In an experiment of Mr. Fairbairn's he found that the shearing force was as nearly equal to the tensile strain as it was possible to get it. When he read the paper he knew there was a slight difference, but he did not think it worth while to retain it in the results. As some of the members had challenged him by saying he forgot that riveted joints were weaker than the plate itself, he might refer to the formula A, B, C, D, E, F, and so on, to

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show that he knew something about that. His calculations very closely agreed with what Mr. Fairbairn had stated in the letter read that night. He (Mr. Baldwin) had read from the shorthand-writer's notes the remarks made by Mr. Barnaby, and he thought there was not very much to answer in them. He found that in a plate that Mr. Barnaby had punched he got $10\frac{9}{16}$ tons as the breaking force, and then, on drilling a piece of iron, he got $11\frac{3}{4}$ tons. Those figures were very close indeed to his own, and he thought there was very little to be said against punching in favour of drilling. It had been said it would be much better for boiler plates to be welded. He had been present at a few experiments with welded joints. He witnessed the experiment which Professor Rankine gave, which was performed at Messrs. Dunn, Hattersley and Co.'s works, in Manchester. The joint was tried by hydraulic pressure, and 30,000 lb. per square inch burst about 2 in. wide just in the weld. When there was a welded joint, and a bursting strain came upon the boiler, the weld must give way. Whatever might be said in favour of welded joints, he was of opinion that they would never be valuable for boilers. The experiments which Mr. Roberts had made completely upset all the speakers who opposed his views. Those experiments told them what his (Mr. Baldwin's) formulæ told them—that the shearing strain and the tensile strain were nearly equal. He had been taunted in the papers about reasoning from incorrect data, but that data was experimental data. Mr. Roberts had said that when a steam-boiler was at work the rivets were under very different circumstances than when they were being experimented with in plates; for when the boiler was working the rivet had not only a shearing but also a tensile strain upon it, and it would give way sooner when it had a tensile strain than when it had a shearing strain alone, when near the point of rupture. In answer to Mr. Pinchbeck's communication, he would say, let him, if he pleased, vary the rivets while the pitch remained constant, or *vice versâ*. That would make no difference. If it were wished to keep a constant pitch throughout the boiler, let the diameter of the rivets be varied. He would now refer to the remarks made by Mr. Olrick about the longitudinal tension of the boiler-plates. If there had been no flues in the boiler, the relative tensions would be as 2 to 1; but the flues took away about half the area of the end of the boiler, and Mr. Olrick had not deducted that. If he had done so, it would have been as 3 to 1, as stated in the paper. Mr. Olrick stated that he (Mr. Baldwin) had made a mistake in the Table where he had a $\frac{3}{8}$ in. plate and a pitch of 1·75 in. He had taken that from Mr. Fairbairn's paper which was read before the Society of Arts. It gave a maximum strain of 58,893 lb. One gentleman

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had spoken about templates. He should be very sorry to have a boiler that was made up by the use of templates alone. The only way in which a boiler with straight joints ought to be made was to punch it with a double punching machine, moving like a planing machine, so that it would punch whatever pitch it was set at. He had had, very recently, three boilers constructed with $\frac{1}{2}$ in. plates and a $1\frac{5}{8}$ in. pitch for the rivets, and the rivets $\frac{3}{4}$ in. in diameter. He had many times seen one of the boilers work at 105 lb. pressure. The diameter of the boilers was 6 ft., and they were 28 ft. long. He tested one of them at a hydraulic pressure of 198 lb. per square inch, and the others were tested up to 160 lb. It seemed to him that the subject of caulking was very badly understood. He should not dream for a moment that the caulking of a joint would bend or injure a plate. The surface between the plates was very small indeed on which the steam acted, being less than the 100th part of an inch, and consequently there was only a pressure of 1 lb. per inch in length in that part when the pressure in the boiler amounted to 100 lb. per inch. The caulking ought to be done very nicely, and not with heavy hammers. Mr. Olrick had stated that the rivets in one instance were put in the form of isosceles triangles, but they were equilateral where the distance was the same every way, and that made a great deal of difference. The joint was better, provided the distance was the same every way. In his Table the distance between the rivets was very small, and, if it was followed, they would get a double-riveted joint of the strongest form. One gentleman had said something about putting the rivets 3 in. asunder. He should try to get away from such a boiler if it had anything like one-fifth of what might be called its bursting pressure in it. He thought it was a mistake to suppose that boiler inspectors were all practical men. Many of them who went about to examine boilers did not go inside to look at them, and that was a very bad examination. He had been inside hundreds of boilers to examine the scale that was deposited upon them, and in many cases he had analysed the scale and found both carbonate of lime and sulphate of lime in it. He had found boilers in the state described in the communication read by the Secretary. They appeared as if they had been cut at the edge of the plates. At Rochdale there were many boilers with small holes in the Lowmoor plate, just over the furnaces, as if small pellets had been taken out of them. Inspectors of the Boiler Association had said that they were caused by the water; others had said they were due to galvanic action; but their origin had never been explained. Where the water was bad and the plate got cut, the iron must go. No doubt many boiler explosions had been caused by corrosion. It had been said that, no matter

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what the strength of the joint was, it was the plate which always gave way first. He regarded the plate as part of the joint, and, if corrosion took place at the joint, the boiler would be weakened at that part.

The PRESIDENT said that the Society might sincerely congratulate itself in bringing out so much information of real practical value upon a subject of such undoubted importance. It had struck him, in following the discussion, that they were in want of more experiments on the strength of riveted joints. No doubt Mr. Fairbairn's formulæ were not far wrong, but there was great variability in the strength of boiler iron. There was reason to believe that a great deal of the iron used fell as low as 15 tons to the square inch.

Mr. ROBERTS: Lower.

The PRESIDENT said, perhaps it was lower, but he was speaking of what would not be considered positively defective iron. No doubt it occasionally went as high as 30 tons. Then there was the variation in the quality of rivet iron, though not to the same extent. It was well known that in America the boiler iron used was much thinner than in this country. He might say as a fact, that, on the leading lines of railway in the United States, boilers worked regularly at 140 lb. or 150 lb. which were made of $\frac{1}{4}$ in. iron and single riveted. Sometimes, but not often, the thickness was $\frac{3}{8}$. It was believed there that those plates were absolutely as strong as considerably thicker plates. He never heard of grooving until he came to this country. He could not attribute the absence of grooving in the United States to anything but the use of thinner iron. The pitch of the rivets was very much the same as in England. No doubt the boilers in America stood as well as those in this country. If the attention of this Society or of its individual members could be directed to bring about a series of experiments, the result would be very valuable.

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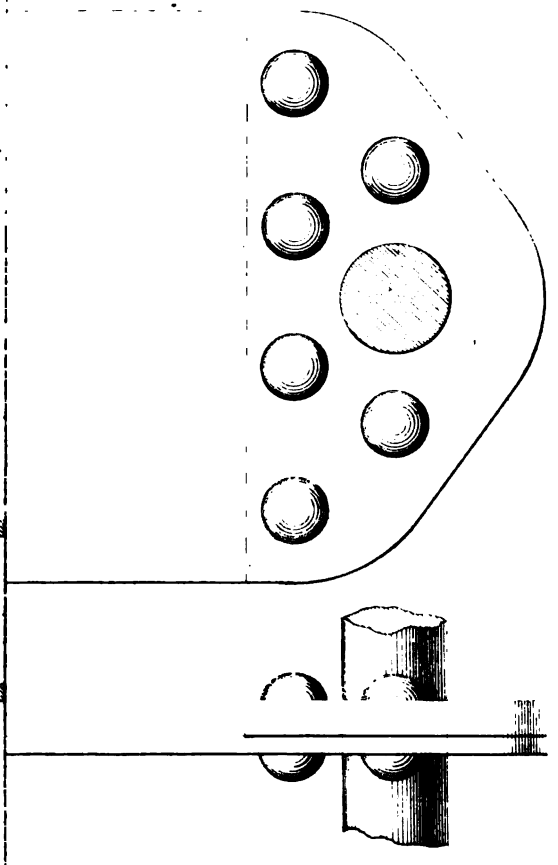

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Plate 11·35" broad. 3/8" thick. 2 3/8" lap, Six 7/8 rivets. 1 7/8 centres, clear section of plate 2.29 sq. in. clear section of rivets 3.6 sq. in. Breaking strain 47.5 tons or 20.74 tons per sq. in. clear section of plate, or 4.18 tons per inch run of joint.

See Mr J Hendry's remarks

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Fig. 3.

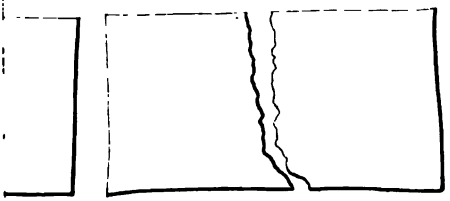
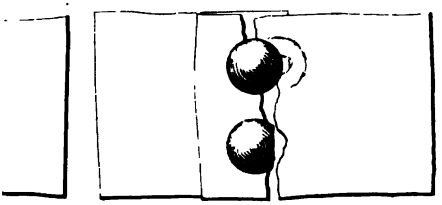
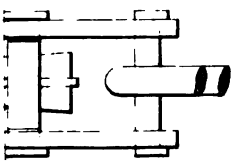
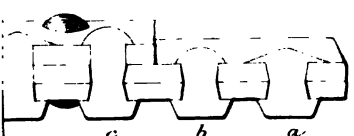


Fig. 6.







See Mr. Roberts' remarks.

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November 5th, 1866.

ZERAH COLBURN, PRESIDENT, IN THE CHAIR.

THE RAILWAY BRIDGE AT LA PLACE DE L'EUROPE, PARIS.

BY THOMAS CARGILL.

As a nation, we undoubtedly enjoy the distinction of having been the first to introduce and adopt the present system of railway engineering. We were the pioneers of steam locomotion in France and on the Continent generally, and are, at this very time, actively engaged in carrying into far distant lands the benefits which have accrued to ourselves, from its constituting the most prominent of our internal resources. Those who are the first to witness the advent of an improvement, whether its origin be fortuitous or otherwise, may naturally be expected to be also the first to imitate it, provided they have the sagacity to distinguish between an improvement and an innovation. Every innovation is not an improvement, nor is every novelty a reform. There are still railways in progress of construction in France whose professional head-quarters are to be found in Victoria and Great George streets; but there is no question that a great proportion of the work formerly designed by English engineers and executed by English contractors is now carried out from first to last by the French themselves. They have now their own engineers and contractors, and we no longer possess a professional monopoly. Viewed in a jealous and narrow-minded light, this may appear a matter of regret, but to the man of enlightened mind, to the engineer anxious for the advancement of his profession, for the diffusion of its utility, and for the universal recognition of the truth and soundness of its principles, it is a subject of cordial congratulation. A vast difference exists between an abstract principle, theory, formula, or equation, and its application to actual practical examples. The former are the embodied results of scientific researches and natural laws, and are unalterable; the latter is susceptible of infinite variations. Given certain theoretical data

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in common, every engineer will deduce an identical theoretical result; but no two will produce an identical practical result. The difference, probably, may not involve any departure from sound and established principles of construction, but it will, in all cases, be sufficiently marked to indicate that the designs emanated from different individuals. Thus, every nation will practically apply those principles of science which it may either have discovered itself, or received from a neighbouring people, in a manner most in unison with its own particular tastes and ideas. Hence arises the diversity of execution attending similar designs, since the character and style of the work will always be, more or less, strongly tinctured with those peculiar habits and opinions which, in fact, constitute a nation's individuality. Consider the influence of succeeding nations upon architecture, and the manner in which various styles sprang into existence among different people. With respect to ourselves, it must be admitted, however unwillingly, that our ideas of architecture are becoming rapidly merged into an appreciation of the capabilities of iron, and all our efforts to maintain its ancient grandeur and beauty are confined solely to ascertaining how far this modern substitute for stone and timber may be rendered subservient to its interests. If an engineer of the present day required an inspiration to complete his design, Vulcan is the only deity he could legitimately invoke to his assistance. A stone bridge, of dimensions sufficient to render it worthy of the name, will soon be a rarity, not only in this country, but on the Continent and elsewhere.

The physical features of a country no doubt exercise a considerable influence upon the most advantageous method of constructing engineering works within its boundaries. So far as iron structures are concerned, they appear to be independent of this influence, for we have erected bridges and roofs in Russia and India, differing in no essential points from those put up in our own country. The introduction of railways and that of iron bridges was contemporaneous. Iron bridges may be divided into two principal classes—viz. those carrying railway traffic, and those carrying ordinary road or street traffic. It is only recently, comparatively speaking, that iron bridges have been employed for the purpose of carrying road or street traffic. They were generally confined, in the early days of railroads, to carrying the railway over an intervening space, and were consequently limited to under bridges. The over bridges were usually built of masonry or brickwork. Latterly, however, this restriction has been removed; and considering the success that has, in every point of view, attended the erection of Westminster-bridge, and the probable success that will also accompany the construction

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of new Blackfriars-bridge, it is almost certain that our next street bridge over the Thames will be constructed of a similar material. An example of the erection of a wrought-iron bridge for the purpose of carrying street traffic has very recently been afforded in Paris. It is the object of the present paper to give a general and detailed account of this recent construction, which possesses some features of peculiar interest to the engineer. The locality where this remarkable structure is erected is known by the name of "La Place de l'Europe," and is appropriately so termed, since it is the common focus to which converge six of the principal streets of Paris, named respectively "Rue de Londres," "Rue de Berlin," "Rue de St. Petersbourg," "Rue de Vienne," "Rue de Madrid," and "Rue de Constantinople." (Fig. 1.) Without reflection, it might be supposed, granting that there was a choice in the matter, that it is bad engineering to run a line across the junction of roads and streets, whereas it is in reality a point to be aimed at in laying out a line of railway, as one bridge thereby answers the purpose of several. It is true that it will probably be larger than any one of the others considered separately, but it is cheaper to build one good-sized bridge than three or four small ones. The late extensions of our metropolitan lines in and about London will furnish numerous examples of the junction of several roads and streets being crossed by railway bridges both under and over. The plan of the bridge evidently owes its peculiar and irregular shape to either the wish or the necessity for preserving the directions of the converging street unaltered. In London, where a glance at the railways is sufficient to convince the observer that the question of utility is paramount to every other consideration, we should unhesitatingly have sacrificed the gardens in the angular portions of the ground, diverted each pair of side streets into the main channels, Berlin and Madrid streets, and, by so doing, reduced the size and cost of the bridge to about a third of its present dimensions and value. There is very little doubt, however, that the engineer had no choice in the matter; a paternal government marked out his ground-plan for him, and all that he had to do was to employ his professional skill and ability in designing the most suitable bridge under the circumstances. In consequence of the bridge being close to a station, viz. the terminus of St. Lazare, there are numerous sidings and turn-outs running in all directions under the bridge. The main lines are, therefore, considered to be parallel to two of the piers and to one of the abutments, and these latter will be referred to as the piers and abutment on the square, and the others as the pier and abutment on the skew. The shape of the bridge on plan (see Fig. 1) may be subdivided into three parts—the central portion, ABCD, and the two side portions

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or wings. The reason for the introduction of the skew pier is not by any means clear; it appears to have been introduced for the purpose of giving an uniformity of span to a number of the intermediate girders, which have the other end resting upon the abutment on the skew, to which it is parallel. It certainly divides the whole distance, D F, at the point J, into two spans; but a single column of masonry or cast-iron pillar would have accomplished this result equally well, without necessitating a continued pier of masonry. The girders may be classed under the following heads—face-girders, or those which can be seen in elevation, looking from the railway on each side of the bridge; intermediate girders, or those running continuously from abutment to abutment; girders in the angles under the converging streets; and, lastly, the cross girders. The face-girders are six in number, two of which CB, CG, are called the central girders, and are the only two absolutely identical in span and other details out of forty-one, which constitute the entire number of main girders, as distinguished from cross girders. The span of these central girders is 82 ft. The remaining four face girders have the following spans: V, or that under "Rue de Vienne," has a span of 137·29 ft.; L, or that under "Rue de Londres," is divided into two spans, of which the shorter is 72·62 ft. in length, and the longer 191·80 ft., being the longest single span of any girder in the bridge. The girder C, under "Rue de Constantinople," is 137·25 ft. in span, and may be considered identical in all respects with that under "Rue de Vienne," as the difference in their relative spans is only 0·04 of a foot, or just half an inch. The other face girder P, under "Rue de St. Petersbourg," has a span of 112·47 ft. With respect to the rest of the main girders the plan of the bridge may be divided as follows: a central portion, comprising all the intermediate girders, and the four angular portions, connected respectively with the girders already mentioned. The intermediate girders, running continuously from the square abutment to the skew one, are nine in number. Of these nine, Nos. 1, 2, 3, 4 are regarded as continuous over three spans, and the remainder, Nos. 5, 6, 7, 8, 9, extend over four. Strictly speaking, Nos. 2, 3, and 4 are continuous over four spans, but the span beween the skew pier and the square one is so small as to be disregarded. It would be to no purpose to give the total span of all of these nine girders; it will be sufficient to mention that the total span from abutment to abutment of the shortest, No. 1, is 304·81 ft.; that of the longest, No. 9, 340·85 ft.; and that of No. 5, 322·81; which may fairly be taken as the average total span of the whole nine. It will be seen that the three same spans in each girder have the same constant length. The span

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from the square abutment to the square pier is constant for the whole nine, and is 98·40 ft.; the central span, from one square pier to the other, is also constant, being 82 ft. in length; and the span from the skew pier to the skew abutment is the same for all, and is 101·90 ft. in length. The variable quantity is the span between the square and the skew pier. The distance from centre to centre of the intermediate girders is 16·72 ft.

Passing on to the girders situated in the angles of the bridge, we will commence with those under "Rue de Londres." They are eleven in all, seven of which rest partly upon the skew abutment and partly upon the face-girder, and have an average span of 64·23 ft. The remaining four bear at one end upon the skew abutment and at the other on the skew pier, and are not continuous over it. They have, therefore, a constant span of 101·90 ft. The distance from centre to centre of the nine intermediate girders is 18·14 ft., being about 18 in. more than that of the intermediate girders. The girders supporting "Rue de Vienne" are five in number, and supported partly by the square abutment and partly by the face-girder. The span of the shortest is 21·95 ft., and that of the longest 97·19 ft. Of those under "Rue de Constantinople" the shortest has a span of 23·40 ft., and the longest of 91·65 ft. Those under "Rue de St. Petersbourg" are also five in number, the first having a span of 7·20 ft., and the last of 102·29 ft. The girders under "Rue de Vienne" and "Rue de Constantinople" are 18·29 ft. apart from centre to centre, and those under "Rue de St. Petersbourg" are placed the same distance apart as the intermediate girders. The reason for these varying distances is probably the desire to divide the spans of the face-girders into a number of bearing points equally distant from one another. The cross girders are arranged parallel to one another, but their respective spans are not constant. Those in the central part of the bridge placed between the intermediate girders have a span of 15·21 ft., and those between the girders in the angles of 18·92 ft. All the face girders are what are known as double lattice girders, and, in order to preserve an uniformity of appearance in the elevation, have the same depth, although their spans vary considerably. The intermediate and the girders under the side streets, with the exception of those under "Rue de Vienne," are also of the double-lattice form, but of a simpler description. The girders in the corners, in consequence of the limited dimensions of their spans, are single lattice girders. The girders resting upon the face-girder V are of the plate form, two of them being single or plate girders proper, and three of them being double, or what are known as box girders. The whole of the cross girders are plate girders.

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One of the principal difficulties to be overcome in the construction of the present bridge arose from the streets being on different levels. It is a common enough observation that "facts are stubborn things." Well, levels are engineers' facts. They cannot be disregarded or got rid of. A diversion of a road or stream may frequently be accomplished in half a dozen different ways, but given a certain height to rise in a certain distance, and there is no choice but to adopt the only gradient that can be got. The rise in "Rue de Vienne" is 1 in 28, the whole rise of the street being obtained in the span of the face-girder V, the roadway continuing horizontal over the central part of the bridge. This difference of level is provided for by constructing the girders resting upon the face-girder with ends of unequal depth. The consequence of this difference of level in the streets is to cause the roadway to be suspended at about the centre, vertically, of the face-girders, and to produce both an unpleasing and unscientific appearance (Fig. 3). The distribution of a load either over the top or bottom of a girder appears, so to speak, natural; but the position given to in the elevation has not only rather an unsightly appearance, but is the very worst position a load can occupy, since it is in close proximity to the neutral axis of the girder. The actual disadvantage resulting from so placing the load depends, in a great measure, upon the amount of vibration exercised by the movable portion of it. In a bridge similar to that at "La Place de l'Europe," where ordinary street traffic has only to be provided for, the concussive action of a moving load may be neglected, as it will be absorbed in the mass of the bridge, whose *vis inertiæ* would more than compensate for any slight shock occasioned by the passage of a very heavy weight. In railway bridges, unless of very large spans, these conditions are reversed, the movable load preponderating over the fixed or static load. The author considers that the face-girder supporting "Rue de Vienne" might have been placed on the incline of 1 in 28, and the central girders raised to the level of the present streets with considerable improvement in point of appearance. The roadway and its support would then appear in their proper relative positions, the centre of gravity of the whole structure, together with its load, would be lowered, and the rigidity of the bridge increased. The cost of raising the piers would be counterbalanced by the reduced height in the abutment, and, if otherwise, the additional expense would be very trifling. The end spans of Lambeth-bridge are upon an incline of 1 in 23·33, and, although it is certainly a hideous structure, yet it is doubtful whether the inclination of the shore ends has anything to do with its want of beauty. The masonry of the Paris bridge presents no features worthy of particular notice. The piers and

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abutments are faced with coursed ashlar, dressed and chamfered, and relieving arches are built in them between the solid pilasters, supporting the ends of the girders. The greatest pressure upon the square abutment is 1·86 tons per square foot; upon one of the square piers and upon the skew abutments 2 tons, and upon the other square pier and upon the skew pier 3·2 tons per square foot. The greatest pressure per square foot immediately under the bearing of any of the large face-girders does not exceed 3 tons.

In a longitudinal section of a portion of the roadway (see Fig. 4), the cross girders are shown 6·56 ft. apart from centre to centre, and between them are turned arches of hollow bricks 9 in. deep and weighing 0·145 ton per foot run. The haunches of the arches are filled in with thin concrete, weighing 0·108 ton per foot run. Over the arches is spread a layer of asphaltum, rather more than ½ in. in thickness, and weighing per same unit of length 0·018 ton. On the top of the asphaltum the metalling is laid; it is 1 ft. in depth, and weighs 0·356 ton. Adding the weight of the cross girder itself, equal to 0·032 ton per foot run, we obtain for the total weight supported by the cross girders per running foot 0·66 ton, or nearly 13¼ cwt. This weight, however, is only constant for the cross girders situated in the angles of the streets and in the end spans of the intermediate girders. Those in the centre of the bridge, owing to the greater depth of metalling, carry half as much again, and may be therefore said to have a load per running foot of exactly 1 ton. Making W to equal the total weight per running foot, and putting d for the distance of the cross girders apart, we find $\frac{W}{d}=0{\cdot}1006$ ton, the weight per square foot of the cross girders and roadway. Adding a proof load of 0·0366 ton, we obtain 0·1372 ton as the total load per square foot. The weight of the main girder is, of course, not included in the above calculations. In a similar manner the maximum weight per square foot, occurring in the central part of the girder, will be found to be 0·1828 ton. The minimum load per superficial foot is therefore 2¾ cwt., and the maximum a little under 3¾ cwt. Of this total load the portion 0·0366 ton represents the maximum live weight per square foot supposed to be brought upon the bridge, and is equal to 82 lb. This is nearly the proportion adhered to in many of our own bridges. In apportioning the live load upon a bridge, the chief points to be regarded are its size and character. A smaller load per square foot may be assumed as the maximum for a large bridge than for a small one, as the effect of any violent and sudden transition of a live weight will be more severely felt in the latter instance than in the former. Again, the situation and

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character of the bridge determine whether the ordinary assumption of the weight of a dense crowd as a maximum load is tenable or not. An iron bridge, especially a lattice, offers peculiar facilities for being loaded to an amount considerably above what could possibly come upon a stone bridge having the same area. Imagine the bridge at La Place de l'Europe under the circumstances attending a public royal departure from the terminus of St. Lazare. It is not too much to assert that not only every inch of space available upon the roadway and footpaths would be occupied, but every part of the sides and top; every nook and corner into which a hand or foot could be inserted would be taken advantage of for the purpose of sight-seeing. Any bridge situated in a locality similar to the one in question is liable to be thus overloaded. The author has seen the chains of Lambeth-bridge covered with a live load, in addition to that on the platform.

The manner in which the final thrust of the hollow brick arches supporting the roadway is disposed of is very ingenious (see Fig. 4). It is manifest that although the arches rest upon the cross girders, yet the thrust of each half arch is resisted by that of its neighbour, acting in the opposite direction. This process of thrust and resistance is continued until we come to the last half arch, which has no fellow to take its thrust. This thrust is not taken by the abutment, as might be supposed, but the following method is employed: The last cross girder, upon which the arch rests, is tied by strong plate braces to the last cross girder but one, at the points of its bearing upon the main girders, thus transferring the thrust to these points. As an additional precaution, the last two arches are tied, the last by a diaphragm, and the last but one by a flat tie rod. This arrangement makes the iron and brickwork to form one complete frame, so that if we were to imagine the whole superstructure lifted bodily off its supports, it would still be self-containing. If the thrust of the last half arches were taken by the abutments, the effects of the expansion, by alteration of the temperature of the main girders, would be accumulated upon them, and the consequences might be serious. By the method adopted, the total expansion is subdivided at every cross girder, and the effect upon each arch is inappreciable.

The limits of a paper of this nature will not permit of a detailed investigation into the proportions and dimensions of the various girders constituting the superstructure of the bridge; and, moreover, there would not be the slightest practical utility in attempting the task. A description of the details of the most prominent will amply suffice to give a clear idea of the manner in which the work is designed and executed, and to multiply

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examples on a smaller scale would be wasting both time and labour. It has been already mentioned that the girder V, under "Rue de Vienne," has the same span as that under "Rue de Constantinople," and since that under "Rue de St. Petersbourg" has a smaller span than both, we shall select the first as a fair type of the three. It is shown in elevation in Fig. 5, and in section in Fig. 6. Its construction is peculiar, and consists of two single lattice girders, connected by a strong vertical diaphragm, but with a small space left between the respective flanges. The span being 137·29 ft., and the depth 16·40 ft., the proportion is very large, being $\frac{1}{8\cdot37}$. It is clear that the girders under "Rue de Vienne" transmit half of their load to the abutment, and half to the main girder V, and that, in consequence of the inequality of these loads, the main girder is very unequally loaded; the greatest weight being brought upon it at one extremity, and the least at the other. The girders are placed 18·30 ft. apart, and in order to find the total amount of the load brought upon the main girder we must first ascertain these weights separately. Taking the weight per square foot of the cross girders and roadway, 0·1372 tons, and multiplying it by the distance, 18·30 ft., we have 2·52 tons as the weight per foot run of the girders V^2 to V^6 (Fig. 2), which is constant for all of them. To find the weight transmitted to the main girder by each of them, let P equal the constant weight of the foot run, and p the weight per foot run of each of the girders itself; making l to equal the span, and W the weight brought upon the face girder by any of those V^2 to V^6, we have $W=\frac{(P+p)\times l}{2}$. In the annexed Table the weights, calculated by this formula, are given with the respective values of the letters:

$$W=\frac{(P+p)\times l}{2} \qquad P=2\cdot51 \text{ tons.}$$

	p	l	W
V^2	0·089	22·46	29·198
V^3	0·119	42·21	55·295
V^4	0·179	61·03	81·780
V^5	0·270	80·50	111·895
V^6	0·323	99·84	140·732

Adding together these separate weights, we find the total load transmitted to the main girder to be 419 tons. The girder itself weighs 82 tons, which will make the total weight it has to

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carry, in round numbers, 500 tons, which is equivalent to 3·65 tons per running foot uniformly distributed over it. From the unequal manner in which the load is brought upon the girder, it cannot be designed upon the usual hypothesis of an uniformly distributed load, and will, therefore, present two principal points of difference in comparison with girders designed on that assumption. One is that the reaction on the supports, and consequently the strain upon the ends of the girder and the lattice-bars, will not be equal at both extremities; the other, that the point of maximum strain on the flanges will not correspond with the centre of the span. It should be remarked here, that the French engineers, in their calculations, have taken the clear span between bearings, and not the distance between the centres of bearings, as is sometimes done. The reactions upon the abutments can be easily found from the principle of the lever, upon which is based all the theory of horizontal girders. Let R and R^1 be the two reactions, taking R to represent the greater, or that upon the square pier, and R^1 the lesser, upon the abutment. If w^2, w^3, w^4, &c., be the weights calculated for the girders, V^2, V^3, V^4, &c., and d^2, d^3, d^4, &c., their distances from the abutment, L^1 the span of the girder V, and W^1 its total weight, we have

$$R=\left(\frac{w^2\times d^2+w^3\times d^3+w^4\times d^4+\ \ldots\ \&c.}{L^1}\right)+\frac{W^1}{2}$$

$$\text{Similarly, } R^1=\left(\frac{w^2\,(L^1-d^2)+w^3\,(L^1-d^3)+\ \ldots\ \&c.}{L^1}\right)+\frac{W^1}{2}.$$

The value of R is thus found to equal 350 tons, and $R^1=150$ tons. It is evident that since the total weight supported by the girder is equal to $(R+R^1)$, when one of the reactions is known, there is no necessity for working out the equation for the other.

The principle adopted by the French engineers in designing the girders is that of determining, firstly, a minimum section of flange which is constant throughout the whole span, and then of adding such additional plates at the centre and elsewhere as the amount of the strains may render necessary. The reverse is the usual method employed by us. We generally first ascertain the maximum sectional area required, and then drop the flange plates accordingly as the decrease in the strains towards the supports will allow. The former method is synthesis; the latter, analysis. The object to be gained in making each girder to consist of two separate girders is not by any means apparent, as all the diaphragms and stiffening in the world would never make the two act like one, and necessarily involves a much larger amount of bracing and extra material than what would be otherwise required. This will be evident on comparing the dia-

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phragm in the sections with the light lattice bracing between the separate bars in the Charing-cross and Blackfriars railway bridges. The diaphragm is composed of a plate $\frac{1}{2}$ in. in thickness, and is riveted all round to angle-irons $4\frac{3}{4}$ in. × $4\frac{3}{4}$ in. × $\frac{5}{8}$ in. To lighten the material a piece of the upper part of the plate is cut out; but although this occasions a slight saving in weight, it causes none in the cost, as the metal cut out would have to be included in the estimate. The distance between the centres of the flanges of each separate girder is 2·46 ft., and the breadth of each flange is 1·47 ft. There is another peculiarity to be remarked in the manner in which the sections are built up. It is the introduction of the angle-irons at the outside edges of the flange plates, which almost seem as if they were placed there for the purpose of covering or protecting the edges. The compression bars are of channel iron, which is undoubtedly the best section that can be used when a large sectional area of strut is required, but it is not so well adapted for bars of a small section. For these, and, in fact, for all ordinary purposes, there is no section which, for cheapness and facility of procuring, can compare with angle-iron. T-iron is also an excellent form of section for large compression-bars, but when used on a small scale there is a loss incurred, in consequence of the necessity of riveting it on both sides of the rib. All the ties are of flat bar iron, riveted at the crossings to the back of the channel-irons. Except at the diaphragms, which are placed about 13 ft. apart, there is no connexion between the webs of each separate girder composing the section. The points of intersection of the struts and ties are $6\frac{1}{2}$ ft. apart, and the greatest length of unbraced strut is a little over 7 ft. The lightest section of channel iron used is 9·84 in. × 2·95 in. × 0·47 in. × 0·51 in., or, as it might be called, $9\frac{7}{8}$ in. × 3 in. × $\frac{1}{2}$ in., having a sectional area of a little above 7 square inches. The section is therefore fully strong and stiff enough to dispense with any intermediate bracing for the above length. The minimum section of this girder (Fig. 6) is built up of four angle-irons, two to each of the separate flanges, of 4·72 in. × 4·72 in. × 0·63 in., or $4\frac{3}{4}$ in. × $4\frac{3}{4}$ in. × $\frac{5}{8}$ in. The author intended to have given all the French measures of angle-irons and plates in their usual corresponding English dimensions, but was compelled to renounce the attempt, as the sectional areas calculated thereby would not tally. It would also have increased the labour very considerably, and involved a double calculation. The few tables available for converting French weights and measures into their corresponding English equivalents are little better than useless for scientific purposes. They serve in some instances as a check for one's calculations, but for nothing more. In addition to the four angle-irons, there are two plates 17·71 in. × 0·47 in., and also two angle-

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irons at the edges 4·33 in. × 2·55 in. × 0·51 in. Of these last angle-irons (Fig. 6) only the horizontal part is included in the calculation of the area. The two side plates are each 17·71 in. × 0·59 in. The total gross area is 63·72 square inches. At the point of greatest strain this area is increased by the addition of extra plates, all 72 in. in thickness to 97½ square inches, the total thickness of flange being 2½ in. The strain per square inch of gross sectional area upon the flange is 3·20 tons. The maximum strain per same unit of area, in any part of the bridge, is not greater than 3·82 tons, and the metal has been apportioned upon this datum. This is rather a high factor of safety, and perhaps accounts for the fact that there is no difference made in the sectional areas of the top and bottom flanges.

The ends of the girders are constructed of plates and angle-irons, and it will be sufficient to investigate the strain upon the heavier end, or that resting upon the square pier. The available material to resist the strain consists of one plate 11·21 ft. × 0·59 in., giving a section of 79½ square inches; of eight angle-irons 4¾ in. × 4¾ in. × ⅝ in., having a total section of 44¼ square inches, and of two vertical plates 2 ft. 4 in. × 0·47 in. The total end sectional area is therefore 147 square inches. The strain upon the heavy end of the girder has been already ascertained to be 350 tons, and we therefore find the metal to be strained to only the amount of 2·31 tons per unit of area. Although this strain is very small, yet it must not be supposed that there is a corresponding loss of material; for the ends of girders, particularly of lattice girders, require to be made extra strong. The principal object to be kept in view in designing the end of a lattice girder is that all the strains brought by the bars upon the end pillars should be conducted to a rigid bearing, and should not have to draw for support upon any of the neighbouring bars. Each of these has its own work to do, and should not be loaded in addition with strains belonging to another part of the structure. There is no doubt that solid end-plates offer the easiest method of accomplishing this result, but, at the same time, it is the most uneconomical. There is no more necessity for a lattice girder to have solid ends than for a plate or box girder to have open ones. In consequence of the unequal distribution of the load, and the point of maximum strain not occurring at the centre of the span, but at the point Y (see Fig. 5), it is here that the load may be supposed to divide, and be ultimately transferred to the supports, in the proportions previously described. The angle of inclination of the lattice bars to the horizon is 44° 6′ 6″, or nearly 1 to 1. The ratio of the strains upon the bars to the vertical strains is therefore as 1·44 to 1. The tie-bars, starting from the point of greatest strain and proceeding towards the

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abutment from 1 to 7, are each 9·84 in. × 0·63 in.; and, since the girder is a double lattice, they are consequently in pairs, and the total sectional area of the pair is 12·38 square inches. The remaining ties completing the web on the same end are all of the same breadth, but the thickness is increased to 0·78 in. The total sectional area of the pair is therefore 15·36 square inches. Proceeding now from the same point towards the pier, all the ties, with the exception of the two nearest to the point of maximum strain, have the thickness of the bars increased to 1·10 in. The sectional area of the pair is therefore equal to 21·65 square inches. The two exceptions are of the same scantlings as the lightest section used at the other part of the web. The channel-iron struts have the same breadth as the bars, and vary in section in proportion with the ties they cross.

They are considered to be also strained to the same amount respectively; but as the nature of the strain is different, their sectional area is proportioned so as to be one-sixth stronger than that of the corresponding intersecting ties. The heaviest section of ⊔ used in this girder is 9·84 in. × 3·46 in. × 0·98 in. × 0·51 in., giving a sectional area of more than 12 square inches. The general formula for the strain upon a pair of end bars is $S = \frac{W}{2 \times N \times \text{sine } \theta}$, where W is the total load distributed, θ the angle between the bars and the horizon, and N the number of systems or series of triangulations in the web. As, however, the load in this instance is not uniformly distributed, and therefore not transferred in equal portions to the supports, we must substitute for $\frac{W}{2}$ its two values of R and R^1 already found. Following the same order with the strains as in describing the bars, and bearing in mind that the reciprocal of sine θ is 1·44, we shall find the strain upon the last pair of bars over the abutment to be 54 tons. Dividing this strain by the sectional area of the bars, it will be seen that they are strained a little less than the stipulated maximum amount, since we shall have about 3½ tons per square inch, instead of 3·82 tons. To find the strain upon the bars upon the other end, we must consider the position of the girder V^6, which is placed at about the distance of 1 ft. from the pier. The weight brought upon the main girder at this point produces no effect upon the lattice bars, and, in fact, scarcely any at all upon that end of the girder, as the strain is practically taken by the pier. Referring to the Table of weights, we find this load to be 140 tons, and it must be deducted from 350 tons, the value found for R^1, before that quantity be used in the formula for the end strain. Effecting this substitution,

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and solving the equation, we shall find the strain upon the pair of end bars to be 75 tons, and dividing as before by the area, the strain per square inch comes out the same as before, viz. $3\frac{1}{2}$ tons. The bars in the web of this girder appear to be proportioned scarcely in so scientific a manner as one would expect, nor is that due attention to the varying amount of the strains in every bar sufficiently shown. For instance, there is no change made in the sectional area of the eight bars, starting from the point of greatest deflection and proceeding in the direction of the abutment. Again, when the section is increased, the remaining bars, six in number, are all of the same section. The principal point to be noticed is the excessive discrepancy between the two bars where the increase takes place. Thus one pair of bars has a sectional area of $12\frac{1}{4}$ in., and the other of $15\frac{1}{4}$ sq. in., a jump of 3 in. in area being made all at once. The discrepancy at the other end of the girder is still greater, the difference in sectional area of two consecutive pairs of bars being over 9 sq. in. It would not be judicious to make the sectional area of the web of a lattice girder vary too closely with the strains, especially in a railway bridge, or whenever the rolling load is large compared with the dead weight, but it should be borne in mind that the web of a lattice girder constitutes its chief economy. If it is not designed in a correct and scientific manner, it would be better to put a plate girder instead, and there are undoubtedly numerous examples of lattice girders which have cost more than plate ones would have done in the same positions. The cause of the jumps in the section of the bars is mainly owing to the very unequal distribution of the weight, and we will consider the respective strains upon the bars of equal section. The minimum strain upon the first eight bars mentioned is about 3 tons, and the maximum 32 tons. Similarly, the minimum strain upon the last six bars towards the pier is 30 tons, and the maximum 75 tons. There is clearly a great loss of material in constructing these bars of equal sectional area. As the rolling load in this bridge is little or nothing, there is no necessity for making the bars at the centre stronger than what is required for a dead load.

The next girder to be described is one of the central girders, which are duplicates of one another. It is similar in appearance to the girder already investigated, having the same depth, with a span of 82 feet, and is represented in elevation in Fig. 7. The total load distributed uniformly, including the weight of the girder itself, is 140 tons. Calculating for the central strain by the usual formula $S = \frac{W \times L}{8\,D}$, we find that $S =$ 90 tons. The section of the central girder is constant through-

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out, and is equal to that of the minimum section of the girder V (see Fig. 6), which has a sectional area of 63·5 square inches. We therefore find that the greatest strain per square inch does not quite equal 1½ tons. The calculations of the French engineers make it equal to 1·48 tons, which is quite clear enough to check the accuracy of the application of the above formula. In the author's calculation, the depth is assumed as 16 ft., and not the extreme depth, 16·40 ft., as the former approaches nearly to the points of the centres of gravity of the flanges, and also simplifies the calculation. About seven years ago, a very interesting discussion arose between Mr. Fairbairn and Captain Tyler, R.E., respecting the correct value to be taken for the depth of a girder in calculating the strains upon it. It was in connexion with the erection of the Spey Viaduct, carrying the Inverness and Aberdeen Railway over the river of that name. Mr. Fairbairn was the engineer for the superstructure of the viaduct, and made use of the total depth in his calculations. Captain Tyler objected to this mode of calculation, and a long and important discussion ensued between them. A blue book was published containing the whole investigation, which is well worthy of perusal. A very good idea may be formed of the discrepancy that can arise between two authorities on a subject, by mentioning that Mr. Fairbairn's calculations gave the strength of his bridge to be 2450 tons, while Captain Tyler only allowed it to be equal to 1954 tons. There were a few other points of difference between them, besides the mere question of the depth, so that the want of identity in their calculations must not be set down wholly to that difference in their data.

The flanges at the centre of the central girders not being subjected to a greater working strain than 1½ tons, and the section being constant throughout the whole length of the girder, the waste of material towards the ends must be very great. The lattice bars have also a constant section throughout, and are inclined at the same angle as those of the preceding girder. The tension bars are all 9·84 in. × 0·63 in., and each pair has therefore a sectional area of 12¼ square inches. The compression bars are of channel iron, and have a section of 14 square inches; or about a sixth in excess of the ties crossing them. Applying the formula for the strain upon the last bars, we find it to be equal to 25¼ tons, which gives just 2 tons as the strain per square inch of area. All the bars lying between this pair and the centre of the girder are of the same section, and it is needless to remark how superfluously strong they must be. The reason—whether justifiable or not, is another matter—why these two girders are so much stronger than necessary, appears to be due to the desire of preserving an uniformity of appearance in

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all the face-girders, and consequently making them all of the same depth. The ratio of depth to span of the central girders is one-fifth, a proportion without a parallel in the history of bridge construction. These two girders afford an example of the evil of departing from "proportion," and of the necessity of closely adhering to its principles in designing all wrought-iron work. It must not be supposed that if we disproportion any one component part of a structure, that the evil ends there, and that the employment of extra material is confined solely to that part. On the contrary, a disproportion in one part entails a disproportion in another; and if we apply a surplus amount of material in one place, we shall be compelled to apply it in another. In the girders in question, the depth being out of all proportion to the span, the flanges must be made considerably stronger than what would otherwise be necessary in order to afford that amount of rigidity and stiffness which the great depth demands. The same reasons apply with greater force to the web, as by its position it is immediately affected by any alteration in the depth to a more serious extent than the flanges. The ends of all the face-girders are constructed in a similar manner, and consist of an upright pillar or vertical box beam, extending the whole breadth of the girder, and made up of plates and angle-irons. It will be observed that the end bars are not attached directly to the pillar, but to a side plate, which is connected with the pillar by angle-irons, and in fact forms a continuation of the side plate of the pillar itself. The thickness of the side plates is $\frac{1}{2}$ in., and the angle-irons may be taken as 4 in. × 4 in. × $\frac{1}{2}$ in. It should be noticed that the plate at the back of the pillar is not continuous throughout the whole height of the girder, but is broken for some distance in the middle.

The most important girder in the whole series is the face-girder of "Rue de Londres," which is represented in elevation in Fig. 8, and in section in Fig. 9. It is designed on the continuous principle, and is divided into two spans of 191·80 ft. and 72·62 ft. respectively. The shorter span is treated as a cantilever, and is loaded at its extreme end with 49·22, or, in round numbers, 50 tons of cast iron. This counterweight is employed for bringing into action the advantages resulting from the adoption of the continuous principle, which is a lightening of the section of the longer span at the point of greatest strain. Owing to the great disparity in the spans and in the rate of loading, the whole girder cannot be considered a favourable example of the application of the above principle.

In the following investigation, the results only of many necessary calculations will be given, as the author has thought it not desirable to introduce intricate and abstruse calculations in

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a paper of a practical character. As the moving load is very small, we may regard both spans as fully loaded, and not concern ourselves with the other assumption of only one being loaded at a time. The total reaction over the intermediate pier will be the sum of the separate weights resulting from each span; and as the spans are both unequal, and unequally loaded, they will have very different values. The reaction due to the longer span is 470 tons, and that to the shorter 185 tons. To resist the greater of these strains we have four plates 16·26 ft. × 0·47 in., giving a total sectional area of 367 square inches. The metal is therefore strained only to the extent of $1\frac{1}{4}$ tons per unit of area. The strain is still less upon the shorter span side, being only 0·82 ton per square inch. None of the metal at the ends of the girder is strained beyond one ton per square inch. Like the other girders, the section of the present one is made up of a constant minimum section, increased where necessary. The minimum section of the longer span consists of one plate, the full breadth of the flange, 4·26 ft. × 0·47 in.; one smaller plate inside, 1·63 ft. × 0·78 in.; four angle-irons, $4\frac{3}{4}$ in. × $4\frac{3}{4}$ in. × 0·47 in.; four side plates, 1·47 ft. × 0·47 in.; and two longitudinal strips between each pair of side plates. These strips are $4\frac{3}{4}$ in. × $1\frac{1}{2}$ in. At the point of the greatest strain, which may be taken to be at the middle of the girder, although it lies really about 9 in. towards the pier, the above section is increased by the addition of three plates, of the full breadth of the flange, having a thickness of 0·59 in., making the total sectional area of rather more than 200 square inches. The greatest strain per square inch at this part of the girder is $3\frac{1}{2}$ tons. The minimum section of the small span differs from that of the larger, in having only two side plates instead of four. The side plates, however, are 0·59 in. thick, instead of 0·47. The total area is 72 square inches. At the bearing over the intermediate pier on the side of the smaller span, this sectional area is increased in the usual manner to 168 square inches. This appears to be considerably more than what is necessary, as the working strain is only 2 tons per unit of area. On the side of the long span over the same pier, one of the three extra plates is dropped; but the working strain is not increased thereby. In the original designs a laborious calculation has been undertaken for the purpose of proving that the bottom plates resting on the pier are not subject to a greater strain than $1\frac{1}{2}$ tons per square inch; but the question is not of sufficient importance to require any notice.

The lattice bars are inclined at the same angle as those belonging to the girder V. In the larger span, the strains upon them may be regarded as dividing to the right and left of

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the point of maximum strain. In the smaller span, they, of course, act in precisely the same manner as in a cantilever. As the manner of calculating the strains upon the bars has been already demonstrated, it will be sufficient in future cases to give the practical results alone. There are three different sections of tension bars used in the small span, having the following scantlings: 9·84 in. × 0·63 in., 9·84 in. × 0·86 in, and 9·84 in. × 0·98. The maximum area of the last pair is 19¼ square inches; and as the strain is a little over 69 tons, the strain per square inch is about 3½ tons. The ties in the web of the largest span vary according to their position with respect to the point of maximum strain. Those on the left hand, lying towards the pier, have four different sections. The first three are of the same breadth as those in the smaller span, but their thicknesses are 0·63 in., 1 in., and 1½ in. The remaining bars close to the pier end are 1·15 in. and 1 in. thick. The maximum sectional area is 43½ square inches, and the greatest strain being 165¼ tons, we have for the working strain per square inch 3·80 tons, or exactly the guaranteed maximum amount. The tension bars lying towards the abutment are all of the same breadth, 9·84 in., but their thicknesses are 0·63 in., 0·86 in., and 1 in. respectively. The greatest strain upon the end pair is 67 tons, and the unit of area carries about 3½ tons. The compression bars are all of channel iron, with the exception of a few crossing the large ties, which are made up of three flat bars 1·15 in. × 0·59 in., and two angle-irons 4 in. × 3 in. × ½ in., the section being too large to be obtained rolled. All the compression bars are designed to bear the same ratio of strain, compared with the ties, as in the girder V. On looking at the difference in the strains at each end of the London-street girder, we find one to be about two and a half times the other, proving how impossible it would have been to design the girder upon the assumption of a load uniformly distributed. All the rivets used are 0·984 in. in diameter, or, as they might be called, an inch, and have an alternate pitch of 6½ in. In the joints in the horizontal flange-plates, the breadth of the plates, or of each thickness of metal, is reduced 6 in., since there are six rows of rivets in a line. Only about four of these pass through all the plates in some cases; but it would not be safe to calculate upon a lesser deduction than 6 linear inches. The joint-plates of the side-plates are 1 ft. 4 in. long, and the rivets have an alternate pitch of 5 in. The side-plate loses 5 in. out of its total depth available for calculation, at the joint. The wrapper does not extend the whole depth of the plate, but only so far until it meets the longitudinal angle-iron, which performs the duty of a wrapper for that part of the side-plate riveted to it. The angle-iron joints are arranged

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so as to have only one rivet-hole out in each flange in the same cross section. So far as the deduction of the rivet-holes is concerned, it is, in the present instance, a matter of no moment, as all the investigations have been based upon the gross area, and it is for this reason that so very low a working strain has been taken, although the simple difference between the gross area and that obtained after deducting the rivet-holes is not sufficient to necessitate the adoption of so high a factor of safety.

Having considered the principal features in the main girders of the bridge, we shall now pass on to those of smaller dimensions. The most prominent of these are the intermediate girders, nine in number, running from abutment to abutment, across the central part of the bridge, and No. 5, being a fair average type of the whole, is the one represented in elevation in Fig. 11, and in section in Fig. 12. In all these girders, the dead weight is not constant for all the separate spans. The two end spans are loaded in a manner precisely similar to that of the girders in the angles of the streets, which bear upon the face girders. The dead load of 0·1006 ton per square foot is, therefore, common to both. The central spans have a heavier load to carry, in consequence of the greater depth of roadway there than at the sides. The girders are placed 16·72 ft. apart from centres, and therefore the weight brought upon them by the cross girders is 0·1006 ton × 16·72, equal 1·68 tons per foot run. The weight of the intermediate girder itself is 0·36 ton per unit of length, and adding to this the proof load, 0·0366 ton × 16·72 ft., we have the total load per foot run of the end spans equal to 2·67 tons. By the same method of calculation, we obtain the weight per foot run of the girders in the central spans to be 3·47 tons, making a difference in the total load on the central spans, compared with the end spans, of 20 tons. The exact spans of the intermediate girder represented in the diagram are 98·40 ft., 82 ft., 14·71 ft., and 101·90 ft., and it is continuous over the four spans. Its depth is uniform, and is 6·88 ft. With the first spans loaded, which will give the greatest strain upon that span, we have the reaction of the square abutment, equal to two-fifths the weight of the whole span, which, knowing the necessary data, we find to be 105 tons. With the first and second span loaded, the vertical reaction of the first pier is equal to the sum of the reactions due to each span, equal to about 320 tons. Similarly, the reaction on the second pier is equal to 155 tons, that of the third to 280 tons, and that on the skew abutment to about 107 tons. The conditions of the strains upon the short span it is needless to consider, as from the nature of the case it must be considerably in excess of the strength which they would require. The

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section of the girder at the centre is composed of flange-plates, angle-irons, and two side-plates, giving a total section of 52 square inches, and is strained to the full amount of 3·82 tons per square inch. At the centre of the span, nearest the square abutment, this section is increased by making the total thickness of the flange-plates equal to 1·65 in., and the working strain is slightly less than that in the central span. At the same point in the span, nearest the skew abutment, the total thickness of the flange-plates equals 1·81 in., the remainder of the section being similar to the other two. The sections over the piers do not differ from the above, with the exception of having the side-plates increased to 0·59 in. in thickness, and that of the flange-plates to 2½ in. The working strain varies from 3½ tons to 2½. On looking at the section of this girder, one cannot fail to be struck with the fact that the distance between the flange-plates of the twin girders, which make up the entire, is but ½ in.

The webs of all the intermediate girders are composed, like those of the main girders, of channel-iron struts and flat bar ties. The bars in the end spans are inclined at an angle to the horizon of 46° 24′ 44″, and those in the central spans of 46° 3′ 18″. The reason for the difference it is difficult to comprehend, as it only has the effect of complicating the workmanship, and increasing the labour of calculation. The ratio of the strains upon the bars to that of the vertical is, in the first instance, 1·36 to 1, and in the second, 1·40 to 1. Both ties and struts have the same constant breadth of 9·84 in., but vary in thickness with the span and their position. The thinnest bar is 0·59 in. in thickness, and the heaviest 1 in. The greatest working strain is 3½ tons per square inch. In order to provide for a small compressive strain, which is brought upon the bars in tension in the central span, according to the position of the moving load, they are also made of channel iron instead of flat bars. The same ratio of strain is preserved between the ties and struts of these nine girders as in the face-girders. The cross girders placed between the intermediate girders in the central part of the bridge have neither the same span nor the same load per unit of length as the others situated between the girders in the angles of the streets. The cross girders in the central part of the bridge have a span of 15·21 ft., and a weight of 0·95 ton per foot run. The most unfavourable case which could occur respecting the action of a rolling load is that of a vehicle weighing 9·8 tons, the transverse distance between the centres of the wheels being 5·57 ft. With the wheels placed, therefore, at equal distances upon each side of the centre of the cross girder, the maximum moment may be found from the equation—

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$$M = \frac{W \times d}{\frac{L}{2}}$$

where W is the weight, L the span, and d the distance from the centre of either wheel to the nearest abutment. All the cross girders may be considered as beams partially secured at the ends, and occupying an intermediate position between those having their extremities rigidly fixed and those whose ends are free. As we have to consider the uniform weight of the cross girder, in addition to the rolling load, in order to find the maximum moment upon it, putting w to represent the weight, we have, making M^1 to equal the greatest moment,

$$M^1 = \left\{ \left(\frac{5}{48} \times w\, L^2 \right) + \left(\frac{3}{16} \times M \times L. \right) \right\}$$

The maximum moment will equal 12½ tons. The section of the central cross girders is made up of angle-irons and a plate-web. The angle-irons are 3½ in. × 3½ in. × ½ in. thick, giving a gross area of 6¾ in. The only difference between those cross girders and those in the angles of the bridge consists in the latter having the greater span of 17·94 ft., and the angle-irons are increased from 0·51 in. to 0·63 in. in thickness. The depth of the cross girders is 2 ft., and the greatest working strain of both classes of cross girders does not exceed 3½ tons per unit of area.

The footpaths are supported by small cross girders, shown in the general longitudinal section, Fig. 6, and those in the centre part of the bridge, between the central face girder and the nearest intermediate, are the only ones requiring any consideration. They have a span of 14¼ ft., and are placed 6½ ft. apart. The total weight each carries, including the weight of the single T irons resting upon it, and its own weight, is 8½ tons. The depth is very nearly one foot. The section is that of a plate beam, and its area is equal to 5½ square inches, which, by calculating by the usual formula for a central section, will give about 3½ tons for the working strain. The single T irons under the footpaths have a maximum span of 8·69 ft., and their distance apart is 9½ in. from centre to centre. They are 3½ in. broad by 4¾ in. deep, and have an uniform thickness of 0·39 in. The T irons in the centre part of the bridge have a span of only 6·56 ft., and are consequently in a more favourable position still.

The four face-girders along the sides of the streets are fixed upon the piers, but are free to move on rollers over the abutments. These rollers are of steel, 3·15 in. in diameter. They vary in length and number under each girder. The greatest number under one girder is 46, with a length of 1 ft. 7½ in., and

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the smallest number 34, with a length of 1 ft. 5½ in. As a proof of the different number considered necessary in our large bridges, it may be mentioned that under one of the large bridges over parts of the Borough, having a span of 180 ft., the rollers do not number more than half a dozen.

More than twenty years ago, it was stated by Mr. Vignolles that the "finical exactness" used by the French engineers and contractors in calculating the quantities of their cuttings and embankments, and the expenses of the various leads, invariably caused the tenders sent in by them to be three or four times the amount of those sent in by English contractors. As a natural result, all the work fell into our hands; and it was certainly owing to this endeavour on the part of the French engineers to substitute theory for practice that paved the way for the introduction of English capital and labour not only into France, but over the whole Continent. There is not the slightest doubt that our neighbours have in a great measure seen the futility of attempting to calculate the expenses of constructing a railway by pure theory; but the author considers the bridge which has formed the subject of the present paper to be a proof that there is some of the old leaven left yet. While all engineers will concur in giving the full meed of praise to scientific calculations, and the due observance of the principles of theory, yet practical men maintain, and justly too, that this point must not be strained too far. In the Paris bridge there does not appear to be that proper consideration given to the workmanship and practical details, a due attention to which can alone ensure an economical construction of any design. One of the chief, if not the chief, principle in designing a structure is to make as much uniformity throughout it as possible. Every foreman is aware how much the execution of any work is accelerated by having as few templates as possible. Throughout the whole number of lattice girders used in this bridge, there are no less than ten different angles of inclinations used for the bars, ranging from 46° to 56°. The only two recognised angles among ourselves are those of 45° and 60°. Others are sometimes employed, but not to any very great extent. The inclination of the bars in the Charing-cross bridge is 45°, and in Blackfriars railway bridge 60°. There are six different sections of angle-iron used, but considering the size and peculiar character of the structure, this number could not be less. The sections of channel iron are five in number. They are all of the same breadth, and it appears rather unusual to insert bars of the same breadth in girders having depths so very different as 6½ ft. and 16½ ft. As the channel sections are very heavy, it was, in all probability, an economical plan to employ as many as possible, and thus save in

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the expense of procuring them. However well the lattice form may answer for railway purposes, it is certainly not so well adapted for the design of a road bridge, particularly when the roadway, as in the present instance, is carried up at some intermediate height between the top and bottom. The appearance of the interior parapet between the lattice spaces is exceedingly unpleasing. So far, however, as the appearance of the present structure is concerned, it is a matter of no consequence, as from its position it can only be viewed from the railway, and one does not expect very fine views from localities of that description. It is not certain whether the employment of the counterweight at the end of the shorter span of the girder L ought not to be considered more as an ingenious expedient—a "tour de force" for carrying out the condition of theory than as a practical method of constructing a girder in that position. It looks, to say the least, somewhat extravagant to deposit between two or three hundred pounds in a lump at one end of a girder, for the purpose of giving it weight. Leaving the question of the proportion of the working strain out of consideration, the investigations entered into have been quite sufficient to establish the proposition laid down by the designer of the bridge, that the maximum strain per square inch of gross sectional area should not in any case exceed the stipulated amount. That this guarantee has been fulfilled, there is not the slightest doubt, but whether it has been fulfilled in the most economical manner is an open question. Engineers are not unanimous in adopting the continuous principle, being aware that it requires a closer approximation of practice to theory than can be always ensured to render it really economical. The mere tying together the extremities of girders over a pier does not necessarily constitute a continuous girder. It has often been alleged against the English engineers that they are too practical. Admitting the statement, it may be said, with equal truth, that the French engineers are too theoretical.

DISCUSSION.

The PRESIDENT expressed the thanks of the society to Mr. Cargill for his paper, and to Mr. C. J. Light for his assistance in the preparation of the diagrams. He said that the thanks of the Society were also in some measure due to M. Clerc, the engineer of the bridge, who, in common with many French engineers, got up his "studies" very elaborately. All the plans of this bridge had been lithographed in a large number of sheets, and they formed a very ponderous volume. The calculations of the strains in the engineer's own way were also published. The fact

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that the design of the bridge proceeded directly from M. Clerc, entitled him to some mention.

Mr. SCHÖNHEYDER said that there was no drawing showing the connexion between the intermediate girders and girder V. As there was a heavy load upon V, it would be very interesting to see how that strain was taken by the girder.

Mr. LIGHT promised that a diagram illustrating that point should be exhibited at the next meeting.

November 19*th*, 1866.

ZERAH COLBURN, PRESIDENT, IN THE CHAIR.

THE RAILWAY BRIDGE AT LA PLACE DE L'EUROPE, PARIS.

BY THOMAS CARGILL.

ADJOURNED DISCUSSION.

Mr. SCHÖNHEYDER said that the paper mentioned an arrangement for taking the thrust of the last arch between the roadway girders, and it was spoken of as a very clever arrangement; but he could not see that the thrust was really taken up. The two last girders were connected by vertical plates, which would no doubt tie them together; and there were a couple of ties underneath the girders tying the last three girders together; but still that would not take the thrust from the third arch. If the third girder were connected by lattice horizontally it would form a stiff girder, and take the thrust. He believed that, generally, any verticals introduced into lattice girders were considered a waste of iron. Those introduced in the Hungerford bridge were very severely commented on. The paper several times stated that the six-way bridge was extraordinarily and unnecessarily strong, and Mr. Cargill remarked that the factor of safety was "very low." It was generally said that the factor of safety was *very high* when a structure was very strong.

Mr. C. J. LIGHT explained that in order to avoid having the thrust of the successive arches thrown in any way upon the abutment, which would be very objectionable on account of the expansion of the ironwork, the engineer had made the superstructure self-contained. Each of the cross girders over the abut-

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ments was connected to the next cross girder by two diaphragms parallel to the main girders, forming three cells for the last arch; and from the ends of these diaphragms the strains were carried by two diagonal bars to the strong points at the connexions of the following cross girder with the main girders. With regard to the verticals of the face-girders, it should be remembered, before condemning them as waste of metal, that they had the important duty to perform of transferring the load brought on them by the secondary girders equally to the top and bottom members of each of the twin girders, which together composed a face-girder. The distribution of the areas in the channel and tie-bars certainly seemed somewhat anomalous. No attempt had apparently been made to keep them down to anything like proportion, whereas, in the other details, the engineer had gone into the most minute calculations. He (Mr. Light) thought that it would have been more useful to have given in the paper the calculation of the strains based, as was usual with English engineers, on the nett area, minus the rivets. The varying angles in the diagonals of the longitudinal girders were no doubt objectionable in the manufacture, but the cause seemed perfectly obvious—viz. the difference in the spacing of the cross girders. The engineer might have varied the vertical depth of the intersecting lines, and so preserved the uniformity of the angles; but whether that would have been better than the course adopted was fairly open to question. He (Mr. Light) wished that Mr. Cargill had given the analysis of one of the most heavily strained diagonals, and compared the area of that bar with the sectional area of the rivets for shearing, and the bearing area of the bar upon them.

Mr. Lefeuvre said that there was no doubt that the bridge was a very ingenious and a very complicated one. He did not, however, see the advantage of having the additional brick pier in the centre, and which was on the skew. It might have been obviated to a great extent by carrying the cross girders through on to the pier immediately adjoining it. In one or two cases columns might have been put in, and the girder made continuous. There was one point which he could not understand in connexion with the road at the end of the girder, called the London girder. Fifty tons of iron placed in the position described seemed quite out of place. He should have preferred utilising the brickwork in the abutment, and anchored the girder down to the abutment, instead of placing fifty tons additional on the top. Nearly half the metal might have been thus saved. Mr. Cargill stated that the placing of the load midway up the girder was very objectionable, but he (Mr. Lefeuvre) was of opinion that if the connexion between the main girder and the cross girders had been

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properly arranged there would be no objection to the load being in that position. Instead of having the cross girders carried by brackets, they would have been carried through the main girder. Great nicety seemed to have been observed in proportioning steel rollers for different loads, but he should have dispensed with rollers altogether, and merely have had rubbing-plates. He had no doubt that after fifty years' use they would be found not to have moved at all. In Hungerford Suspension Bridge the saddles which connected two links on the towers were placed on steel rollers, and Mr. Brunel thought they could act and allow for the moving of the platform; but when they were taken down to be forwarded to Clifton it was found that, although these rollers had been placed in oil, they had not moved at all perceptibly.

Mr. LIGHT explained that this mode of connexion was only adopted in the case of the cross girders under the footways. It was no doubt objectionable, but these girders had only a very light duty to perform. They were spaced two metres apart, and were connected to a longitudinal which was bracketed on to the verticals of the face-girders, these being four metres apart.

Mr. H. P. STEPHENSON said he quite concurred with Mr. Lefeuvre as to the impropriety of the position of the skew pier. In criticising the bridge, however, in the absence of the engineer, they were under a difficulty; for possibly those points which seemed strange were capable of explanation. In the absence of information from the engineer, he quite agreed with the author of the paper as to the extreme amount of metal which appeared to have been used in the girders of the bridge; and without a very good reason being urged in favour of the use of so much metal, he would be inclined to think that a great amount of it was superfluous. The only other point which occurred to him as being objectionable was that a great weight had been placed upon the roadway and footpath. He should have been inclined to have dispensed with a large amount of that weight, and substitute wrought-iron buckled plates, or, better still, buckled steel plates, placing a small amount of gravel above them.

Mr. OLRICK said that he agreed with Mr. Light, that if Mr. Cargill had, in that part of his paper referring to the strains and the different proportions of the girders, compared the more simple manner adopted by English engineers with the complicated French method, it would have been more useful. It seemed that although the French engineers had used such minute calculations, they had not been very successful in arriving at an uniform strain throughout the bridge. The strain varied from 4 tons to about 1½ tons per square inch of area. Mr. Cargill had stated that he had an impression that French engineers were

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too theoretical, and English engineers too practical. That was no doubt very correct; but what he had said about French engineers might be said of all continental engineers. He (Mr. Ölrick) had had some experience of continental engineers, and he could fully corroborate this statement. Practical formulæ based on actual experience were far more valuable than such formulæ as were used in France. There was one redeeming feature in the French calculations, which was the use of decimal fractions instead of our fractions of inches, &c.

Mr. Batley said that by means of the formula he was in the habit of using at Mr. De Bergue's, of Manchester, the whole calculations for a bridge might be performed in an hour, or an hour and a half. The strains and the material necessary to meet them were very simply shown. There was a feature in the girders of the bridge which he certainly did not like. The lattice bars of the face-girders were placed rather more than two metres apart, and, consequently, there were but few intersections of the bars. Had the distance been only one metre, the whole of the material in the upper and lower beams and in the tie-bars could have been considerably reduced, and the total weight of the bridge would have been less. There was also waste material in the ends, there being more than necessary to obtain strength and keep the top and bottom girders in position. The lattice bars crossed only once, and did not meet at the upper and lower ends. Thus an extra strain was thrown upon the top and bottom girders which ought to have been entirely taken up by the tie-bars; for the tie-bars were supposed to carry the weight by the alternate ties and struts from the centre of the bridge to the abutments, and discharge it there. In this case there was a twist at the ends of the tie-bars, and this had a decidedly injurious effect. From the quantity of material employed in the bridge there would be no fear of anything happening to it in consequence of the position of the lattice bars; but still safety was attained by the use of surplus material. In the face-girders the engineer had adopted the method of corrugating the upper portion of the vertical member of the top and bottom girders where the lattice bars joined. The object of this was doubtless to save material; but, while the weight was not reduced very considerably, there was a large additional expenditure of labour.

Mr. Light said he thought there could be no doubt that if the intermediate girders were severely strained, the twisting effect of the diagonals referred to by the last speaker would be injurious to the top and bottom members.

Mr. Lefeuvre said there was one remark towards the close of the paper which ought not to go uncontradicted—viz. that Eng-

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lish engineers, as a rule, were not favourable to continuous girders. He thought that the continuous principle ought to be introduced wherever it was possible. Less material was employed than in other systems. He could not see why it was not equally applicable to road bridges as well as railway bridges, though Mr. Cargill had stated it was not.

Mr. SCHÖNHEYDER said that the steel rollers which had been condemned by Mr. Lefeuvre were intended to provide for the expansion of the bridge, which, in a bridge 400 or 500 ft. in length, such as had been described, would not be less than 4 or 5 in. In the case of the Britannia-bridge, which was carried on rollers, the expansion was shown to be very considerable. According to Mr. E. Clark, the greatest range of temperature in Great Britain is about 135° (15° below and 120° above zero); and, as wrought iron expands ·000,007 of its length for each degree of Fahrenheit, a bridge 400 ft. long would, when at a temperature of $+120°$, be $\cdot 000{,}007 \times 135 \times 400 = \cdot 378$ ft. longer than when at a temperature of $-15°$, $\cdot 378$ ft. $= 4\cdot 536$ in. A 500 ft. bridge, under the same conditions, would expand $\cdot 4725$ ft. $= 5\cdot 67$ in.

Mr. LEFEUVRE replied that he had not proposed to dispense with the rollers without providing a substitute. He had suggested the use of rubbing-plates instead of rollers. These would be sufficient to provide for the expansion in a bridge of the size of that under discussion.

Mr. LEONARD said that he must differ from the last speaker in reference to expansion. He knew an instance of a bridge working over an opening of only about 50 ft. span in which as much as $\frac{7}{8}$ in. had to be cut off the rails to allow for the expansion of one day. In reply to the President, the speaker added that the rails, when laid down, were exactly the same length as the bridge. The rails met when the bridge was closed.

The PRESIDENT said that it was usual not to allow more than $\frac{1}{8}$th of an inch for expansion on a 25 ft. rail.

Mr. OLRICK said that a friend of his had measured the length of one of the girders of the present Charing-cross bridge in the middle of a hot day, and in the night of a cold day, and in a span of 154 ft. the difference caused by expansion was half an inch.

Mr. CARGILL, in replying to the discussion, said that the first point noticed was the successive thrusts of the arches carrying the roadway. Mr. Light had kindly saved him (Mr. Cargill) the necessity of explanation on that point. The gentleman who raised the point did not seem to bear in mind that the thrust was tied back into the main girder, and not shifted simply from one cross girder to another, or the tying would have to be continued over the whole breadth of the bridge. The Charing-cross bridge

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had been mentioned as a case in which the verticals or uprights were supposed to be superfluous, as they undoubtedly are; but in the bridge at La Place de l'Europe they transferred the strain over the top and bottom members. He did not quite understand Mr. Light's remark in endeavouring to explain the difference of the angles of the bars of the web in the various parts of the bridge. He could not see that they had anything to do with the load whatever. The effect of the rivets in diminishing the area of the bars was very small indeed. Mr. Stephenson was unable to see the reason why the skew pier had been introduced. He (Mr. Cargill) agreed with him that it did not seem necessary. If it was for the purpose of shortening the five girders, that might have been done perfectly well by cast-iron columns or pillars of masonry. The use of rollers had been objected to. Rollers were very well if they could be depended upon to move when required. Five or six years ago the Boyne Viaduct in Ireland was lifted off its bearings at one point to restore one of the piers to the perpendicular, and it was found that the rollers were clogged and immovable, and it is clear that the same thing might happen to rubbing-plates. Mr. Stephenson had remarked that the weight of the roadway was excessive, and he proposed the use of buckled plates as at Westminster-bridge. No doubt there was a large amount of surplus weight on the roadway, but there was less than there appeared to be; for the bricks used were hollow or perforated. Although the engineer had adopted arches, he had evidently tried to keep the roadway as light as he could. He (Mr. Cargill) thought that there was something incongruous in applying brick arches of the kind here used on lattice girders. It seemed to be putting a very heavy superstructure on a very light foundation. One gentleman had said that by the use of ordinary formula the calculations for a bridge might be made in an hour and a half. That might be done where the span was a short one and the bridge was uniformly loaded; but when the weights were placed at irregular distances it was quite impossible to reduce them to one of the simple cases, and the calculations must become tedious and lengthy. The same gentleman said that the bars should have been put closer together. He (Mr. Cargill) should have done just the contrary. When lattice girders were first made the bars were very close; and in the bridge over the Royal Canal, Dublin, which was one of the first iron lattice bridges made, the bars in the girders were so close that the girders might almost as well have been of the plate form. The distribution of strains in the web of lattice girders and their accurate determination were then unknown. To the girders with numerous bars and frequent intersections succeeded the Warren girder, and that type

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miserably failed, one of the reasons being that the struts were cast iron. True economy was obtained in lattice girders by the correct distribution of the distances and the correct number of bars. He was sorry that Mr. Lefeuvre did not agree with him respecting the question of the continuous girder. Two of the largest bridges in London were not on the continuous principle, namely, Charing-cross bridge and Blackfriars railway bridge; and there was a bridge on the continuous principle—the Cannon-street bridge, but this had plate, while the other two bridges had lattice girders. It was not sufficiently borne in mind that the continuous girder shifted the points of the strains without tending much, in many instances, to affect their amount. Of course it gave the advantage of shortening the span, and for this reason it had received the credit of possessing many other advantages which do not really belong to it. Taking the bridges over the Thames, the balance was in favour of the discontinuous principle. Mr. Olrick's remarks about the French figures were very specious. He considered that it was much easier to convert them into the sectional area than the English figures; but that was not a proper criterion; for before we could adopt the French method of calculating the areas of angle or other forms of irons, we must adopt their sections. After the experience which he (Mr. Cargill) had had in preparing the paper, he did not think there would be any advantage in adopting the French system of calculations. The English unit was a ton per square inch; the French unit was so many kilogrammes per square millimetre; and this, being less simple than the English unit, involved more trouble in calculating.

Mr. Batley said, that when he asserted that, by a formula which he used, the calculations for a bridge could be made in an hour and a half, he was not referring to small bridges, but to bridges of from 600 to 900 feet run, with only three spans.

Mr. Light said that Mr. Cargill seemed to challenge his statement that the different angles of the diagonals were necessitated by the different spacings of the girders. The angles of the diagonals were dependent upon the spacings of the verticals, which varied with those of the cross girders, as these latter were attached to them.

The President said the paper had given a very interesting example of French constructions, and it was a very great credit to the Society. The reason why the skew pier was adopted was, probably, the necessity for keeping the lines of railway in their original position without changing their direction. One of the girders would have had nearly 270 ft. span without that pier. The space enclosed by the walls was used by the signalmen to keep their lamps in. It seemed to be hardly fair to criticise the

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bridge without knowing the requirements which had to be met. The engineer was expressly forbidden from interfering with the direction or level of any of the streets. It was very natural that he should like to keep the face-girders level and of uniform depths, and probably nine engineers out of ten would have done the same. M. Clerc, the engineer, had sent him (the President) some observations upon the paper, and out of justice to M. Clerc he would read them to the meeting:

The following is the communication received from M. Clerc, the engineer to the bridge, in reply to some of the observations contained in the paper. With respect to the varying distances of the under girders, M. Clerc remarks:

"Ces écartements variables sont motivés par la condition de diviser, en parties égales, les poutres de rive et non les poutres intermédiaires."

Upon the uniformity of depth given to the face girders, we have the following observation:

"Sans méconnaître la valeur des objections présentées, nous doutons que la solution proposée par l'auteur eût été plus satisfaisante. Il nous a paru que l'adoption de poutres de tête de même hauteur était nécessaire pour donner à l'ensemble de l'ouvrage un aspect à peu près régulier."

The engineer for the bridge differs from the author of the paper respecting the distance between the girders V^2 to V^6, and observes:

"Il est impossible de réaliser, ainsi que le fait remarquer d'ailleurs l'auteur du travail, l'état idéal qu'il indique. Il faut nécessairement s'arrêter à une division. Dans celle que nous avons adoptée, la distance qui sépare les poutres V^2 à V^6 ne nous a pas paru trop considérable, et elle a l'avantage d'être à peu près égale à celle qui sépare les poutres de la partie centrale entre elles."

With respect to the two methods adopted by French and English engineers in calculating the sectional areas, M. Clerc remarks:

"Les deux méthodes me paraissent également pouvoir être considérées comme analytiques, du moment que l'on commence par déterminer la valeur des tensions et que l'on en déduit les dimensions des tôles; la synthèse serait, si on se donnait *à priori* les dimensions d'une poutre et que l'on déterminât ensuite les efforts que chaque partie supporte.

"La différence entre les deux méthodes consiste seulement dans le point de départ, mais les résultats sont les mêmes.

"L'avantage du système adopté est une simplicité de construction extrême et une économie notable dans les couvre-joints qu'une poutre unique eût nécessité."

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It will be seen that the use of the angle irons on edge is as surmised by the author, for:

"Les cornières sont destinées à masquer les surépaisseurs des tôles de couvre-joints dans les poutres en élévation."

The difference in the working strain of the compressive and tensile parts of the bridge are also mentioned in:

"Dans les tôles de brides nous admettons le même travail pour les parties travaillant à l'extension et celles travaillant à la compression. Dans les barres de treillis nous admettons, pour les barres comprimées, un travail inférieur d'un sixième à celui des barres tendues.

"Si l'on tenait compte d'une différence analogue pour les brides, l'épaisseur des brides supérieures devrait être augmentée; au lieu d'arriver à une économie, on aurait une augmentation de poids."

M. Clerc has not quite understood the meaning of the author with regard to making the ends of open web girders solid-sided, as he observes:

"Il nous paraît difficile de saisir ce que l'auteur a voulu dire au juste. Il nous paraît que nous sommes d'accord pour renforcer les extrémités des poutres à cause des réactions des appuis. Le moyen de parties pleines que nous avons employé nous paraît le plus simple et le plus rationnel, et il est évident que nous arrivons au résultat que nous nous proposons en faisant pleines les extrémités des poutres à treillis, tandis que ce ne serait guère le moyen d'y arriver pour une poutre tubulaire que de lui donner des extrémités à jour.

"Nous avons adopté pour les barres de treillis une largeur uniforme, en faisant varier seulement leur épaisseur, ce qui nous a paru la condition la plus facile à remplir pour la fabrication. Toutefois, nous n'avons pas cru devoir faire varier cette épaisseur à l'infini, suivant les résultats des calculs, et nous avons adopté un certain nombre de sections moyennes que nous avons appliquées, de manière à rester dans les limites indiquées par le calcul. Nous ne croyons pas qu'il en résulte une déperdition de poids aussi énorme que l'auteur paraît le supposer. En tous cas, nous ne saurions ici encourir le reproche qui nous est adressé dans l'ensemble du travail, c'est-à-dire, d'avoir tout sacrifié à la théorie et d'avoir multiplié à l'infini nos gabarits. Dans la partie de la construction dont il est question, on nous reproche, au contraire, de ne pas avoir suivi d'assez près les résultats du calcul et de n'avoir pas employé un assez grand nombre de sections. Il faut reconnaître qu'il paraît difficile de satisfaire l'auteur du travail."

The following is the remark of M. Clerc respecting the great proportional depth given to the central girders:

"Nous avons, en effet, eu en vue de donner une uniformité

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d'aspect à toutes les poutres de tête. Il faut reconnaître que cette hauteur donnée aux poutres de tête de la partie centrale appelle la critique. Chacun peut apprécier la question à des points de vue différents. Pour nous, nous avons pensé que le point de vue auquel nous nous sommes placés méritait d'être pris en considération, d'autant plus que les épaisseurs des tôles étant considérablement réduites, les poutres de tête, au lieu de donner lieu à un excédant de poids considérable, comme le suppose l'auteur du travail, présentent, au contraire, et cela doit être, une diminution de poids sur les sections que l'on aurait été obligé de leur donner si l'on avait conservé la même hauteur que pour les poutres intermédiaires de la partie centrale."

The impossibility of adopting a greater uniformity of parts is alluded to in the remark:

"Tout le monde est d'accord sur ces principes; mais pour pouvoir observer une uniformité absolue, il faut que les données du problême à résoudre soient elles-mêmes uniformes. Dans le pont de la place de l'Europe, toute la partie centrale présente l'uniformité la plus complète: mais il était impossible, ou du moins nous pensons que cela l'était, de maintenir cette uniformité dans les parties triangulaires où les directions et les pentes des rues sont toutes différentes et ne peuvent être, en aucune façon, modifiées."

M. Clerc thus accounts for the departure from the angle of 45° in some of the diagonal bars:

"L'angle, adopté généralement pour les barres de treillis, est de 45°, et la presque totalité du pont est établie avec cet angle. On a dû, par suite de l'augmentation de hauteur donnée à quelques poutres sous les parties triangulaires, pour racheter la pente des rues, augmenter un peu cette inclinaison, ainsi que dans certaines divisions des poutres intermédiaires, pour racheter les différences de longueur totale entre les culées provenant du nonparallélisme de ces culées; mais ces différences ne s'appliquent qu'à une très petite partie de treillis, et l'on peut dire que, dans la presque totalité du pont, les inclinaisons des treillis sont les mêmes. Faire autrement, c'eût été de créer de gaîté de cœur des complications nouvelles."

It is manifest from the following observation that the opinion of the author and of M. Clerc are not the same respecting the value of the counterweight at one end of the girder:

"Le contrepoids placé à l'extrémité de la poutre L a, pour résultat, d'économiser aux moins 80 tonnes de fer et, de plus, de placer la grande portée dans des conditions beaucoup plus rationnelles pour résister aux charges qui lui sont appliquées, qu'elle ne l'eût été posée librement sur deux appuis."

The concluding remark applies to the principle of continuity:

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"Je ne saurais partager cette manière de voir. Le principe de continuité des poutres exige des calculs assez compliqués devant lesquels certains ingénieurs reculent. Mais il y a, sous le rapport du poids de la matière, un avantage énorme à l'appliquer au lieu d'adopter des poutres libres. En outre, les poutres encastrées se comportent infiniment mieux que les poutres libres sous le rapport de la flexion."

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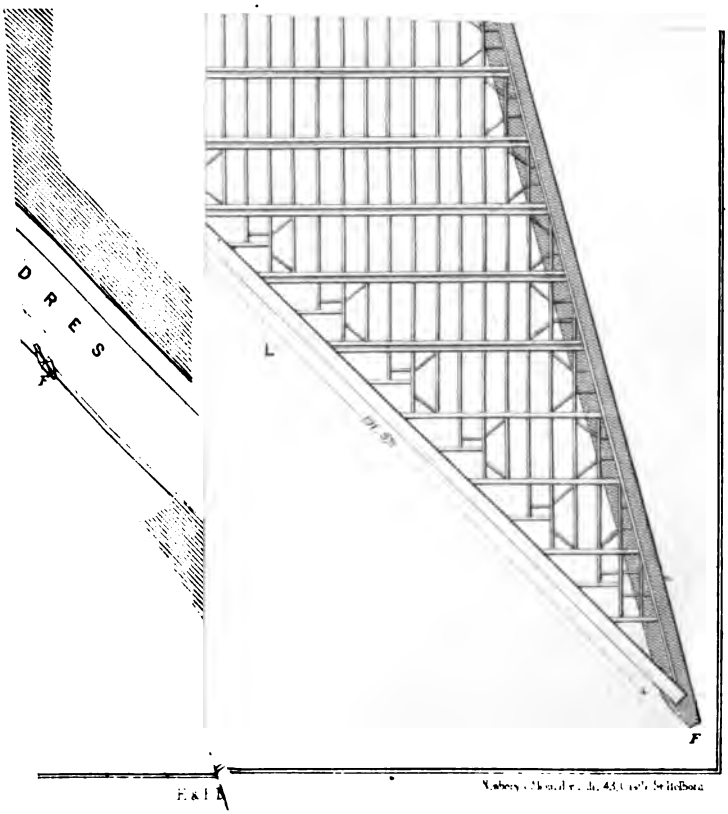

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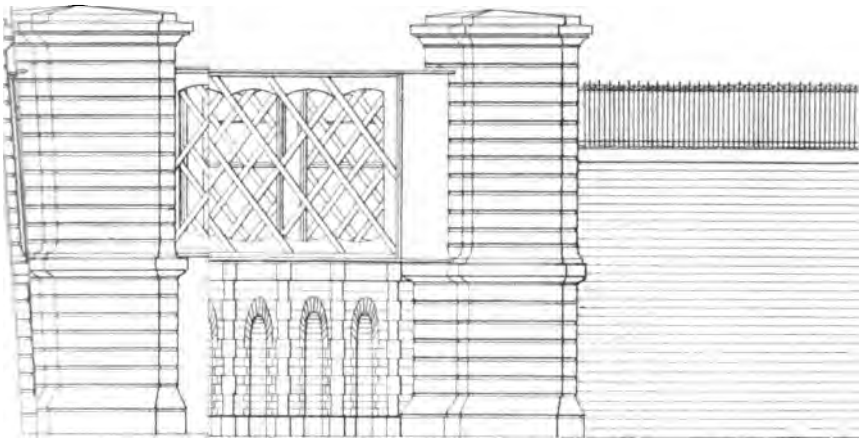

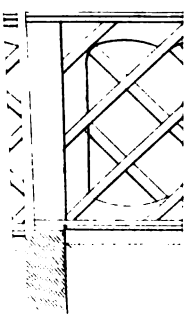

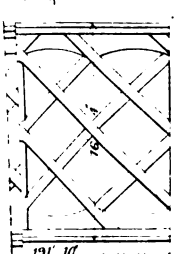

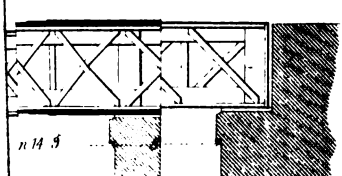

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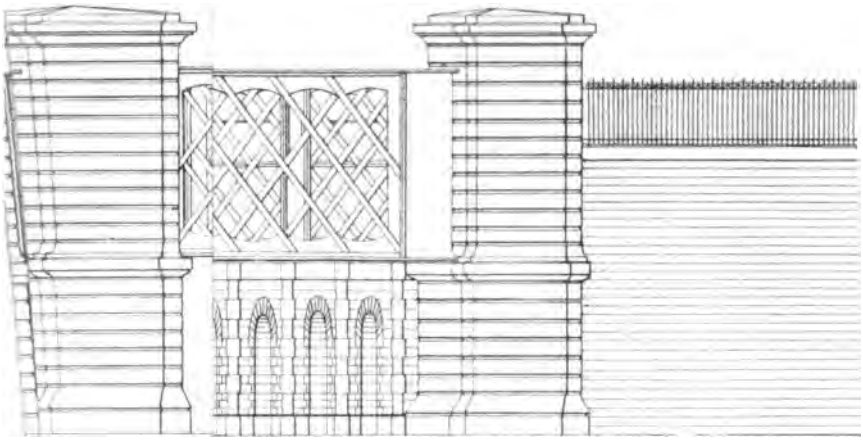

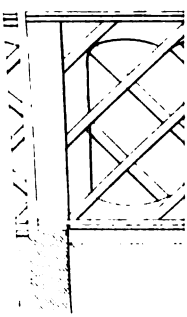

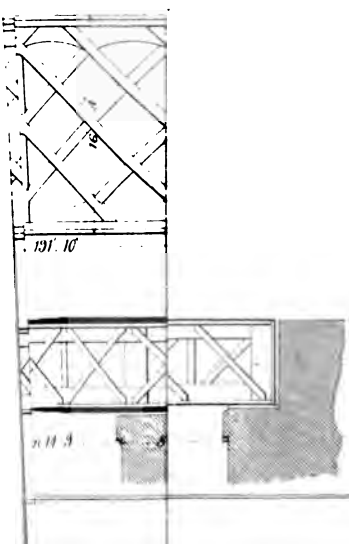

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Fig. 9.

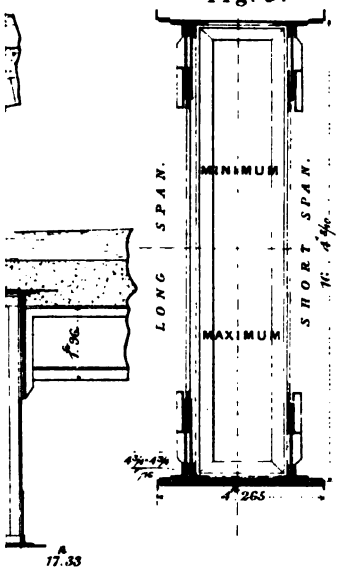
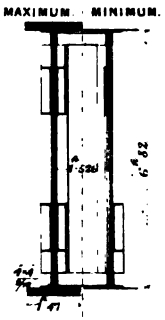
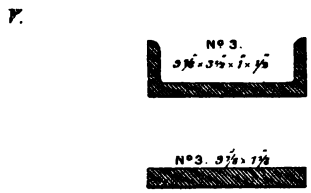
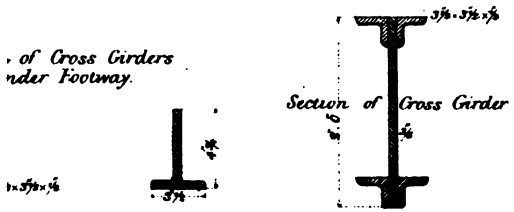


Fig. 12.







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December 3, 1866.

W. H. LEFEUVRE, VICE-PRESIDENT, IN THE CHAIR.

ON THE DESIGNING AND CONSTRUCTION OF STORAGE RESERVOIRS.

BY ARTHUR JACOB.

BEFORE entering upon such considerations as affect the selection of reservoir sites and their construction, a brief allusion to some of the most ancient works for impounding water may not be uninteresting. Of these the most prominent examples are undoubtedly to be found in Hindostan, where the magnitude and antiquity of the storage works cannot fail to arrest attention. These great works, surpassing in their immensity what are conventionally esteemed to be the wonders of the world, the productions of other countries and nations, took their origin in the necessities of the people and the variableness of the climate of India, and were, in fact, great public works on which the welfare of the people mainly depended. The climate of India, although singularly uniform in some respects from year to year, is remarkably variable as regards the rainfall; and in order to guard against the disasters of famine and sickness, inevitably attendant on a a scanty monsoon, the native princes were wont to make such provisions as large resources and an almost unlimited power enabled them, in order to obviate the difficulty that they had to contend with.

The rain records of India for several years past show that scarcity of rain is indicated by periods of about five years, or that every fifth or sixth year is marked by a scanty rainfall over certain districts. The recurrence of these periods is, of course, not very clearly marked, but still it is sufficiently so to warrant, with approximate correctness, the prediction of scarcity and famine; and such deplorable recurrence is, as all are aware, now reigning in India, and visiting with destruction, by sickness and hunger, some thousands whose sole dependence is upon a fair season of rain, and the successful maturing of their little crop of grain.

The natural expedient for guarding against the recurrence of

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these periodical calamities was evidently to be found in husbanding a scanty supply of rain-water for the purpose of irrigation, and this the people of India appear to have understood. They took advantage, in certain districts, of every nook and ravine, whether large or small, and converted them into storage reservoirs by throwing across banks of earth, or *bunds*, as they are termed, producing, in certain districts, such an elaborate and complete system of irrigation as can only be compared, for cost and completeness, to our railway system in England. Taking fourteen districts in the Madras Presidency where tank irrigation was most generally relied upon, the records of the Indian Government show that there are no less than 43,000 irrigation reservoirs now in effective operation, and as many as 10,000 more that have fallen into disuse, making a total number of 53,000 storage works. The average length of embankment is found to be about half a mile, the extreme limit of the series being a dam of the immense length of 30 miles. This ancient reservoir, called the Poniary tank, is no longer in use, the cost of maintaining such a length of bank in adequate repair having probably been found disproportionate to the advantage derived from the supply. The work, embracing an area of storage of between 60 and 80 square miles, remains however as a record of what the Hindoos are capable of. To quote a second example, there is the Veranum reservoir, now in actual operation as a source of supply, and yielding a net revenue of no less than 11,450*l.* per annum. The area of the tank is 35 square miles, and the storage is effected by a dam of 12 miles in length. In order to bring the immensity of this system of storage works within the reach of statistical minds, it has been calculated that the embankments contain as much earth as would serve to encircle the globe with a belt of 6 ft. in thickness. To show that these are not singular examples, one other embankment of remarkable size may be alluded to. This embankment, of somewhat singular construction, was built on the island of Ceylon, and bears testimony that the Singalese monarchs were not behind their neighbours in public spirit or enterprise. The embankment was composed of huge blocks of stone strongly cemented together, and covered over with turf, a solid barrier of 15 miles in length, 100 ft. wide at base, sloping to a top width of 40 ft., and extending across the lower end of a spacious valley.

Thus it will appear that the practice of embanking across valleys, for the purpose of retaining the surface water, has for ages been in operation. There is no doubt that the disposal of some of the most remarkable works in India is not what it might, with advantage, have been; the fact remains however that the desired end was attained, and if the earthworks were dispropor-

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tionately extensive, it was a source of satisfaction at least for the projectors to know that they cost, as a general rule, little or nothing, the practice in those days being to press whatever labour was required, rendering in return nominal wages or none at all.

The two main questions that it is proposed to submit for consideration are, first, the selection of a reservoir site; and, secondly, the leading principles to be observed in the designing and construction of storage works.

The purpose or purposes for which the work may be required will, of course, affect materially the choice of a position, as well as the details of the structure itself; but certain general principles are available for our guidance in every case, after considering which, it is proposed to dwell upon such points as apply to the special purposes for which reservoirs may be constructed.

The first and most essential point for accurate determination by the engineer is undoubtedly the amount of rainfall, both maximum and minimum, that may be expected in the district under examination; and, having arrived at reliable data on this point, the next consideration will obviously be, what amount may be made available, due allowance having been made for evaporation and absorption. When we know that the annual depth of rainfall taken all over the world varies, according to the locality, between zero and 338 in. or 28 ft. deep (which excessive amount was on one occasion registered in the hill district of Western India), it will be obvious how little ground there will be for assumption, in the examination of any district hitherto unexplored, with regard to the question of its rainfall. In the examination of any given country, however, there are certain phenomena connected with the rainfall that will be found of almost invariable acceptation, and may with advantage be borne in mind.

The rainfall will, as a general rule, be greatest in those districts that are situated towards the point from which the prevailing winds blow. If Great Britain for instance be taken, the western districts will be found the most rainy. The very reverse however of this phenomenon is noticed in the neighbourhood of mountain ranges. If the wind prevails from one side rather than from the other, it is found that the greatest rainfall is on the leeward side of the range, and the probable solution of the matter is, that the air, highly charged with moisture, is carried up the hills by the wind until it comes into a cold region of the atmosphere. Condensation of the watery vapour immediately takes place, and the result is a fall of rain on the side of the mountain range remote from the prevailing wind.

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To this cause may also be attributed the fact that the rainfall is always greatest in mountainous districts, while it by no means follows that elevated plains are more abundantly supplied with rain than land lying nearer to the sea level. The principles are remarkably exemplified in the southern part of the Bombay Presidency, where the author has had occasion to study the subject of rainfall. The Western Ghauts run parallel to the coast, rising to a height of 4500 ft. above the sea, and form the western support of the great table-land of the Deccan, the mean elevation of which may be taken at 3000 ft. In the rainy season the south-west monsoon, blowing from the sea, impinges against the ghauts, and while passing onwards to the Deccan, parts with its moisture to the average annual amount of 254 in. On a spur of mountain that runs eastward, the pluviometers are found to register but 50 in.; and about 40 miles farther inland the rainfall is not more in some places than 15 in., which is considerably less than that registered in the lower-lying districts of the Presidency.

In civilised countries like our own much valuable information is usually available regarding the rainfall, if not applying actually to the district under examination, then probably to some neighbouring district, enjoying the same physical characteristics; but when any project of great importance is in contemplation, it will not be sufficient to take the returns of adjoining districts as accurate information of the rainfall at the exact locality fixed upon for the construction of the works. It will be necessary to establish rain-gauges at different points over the catchment basin of the valley from which it is intended to obtain the supply; and daily observations of these gauges must be taken for comparison with a series of simultaneous observations taken and recorded at the nearest station at which the rainfall has been regularly and carefully noted. It is evident that a comparison of the several observations taken over the area of water-shed with those registered at the permanent station will convey a just estimate of the amount of maximum and minimum rainfall that may be relied upon.

The amount of rain falling upon the ground is not, however, the point to be determined, though it will aid considerably as a guide to the engineer. A considerable quantity of all the rainfall is either absorbed by the ground or evaporated before it reaches the point at which it can be made available for storage. Regarding then first the question of absorption, it must be apparent that no two districts, unless they are exactly identical in soil, inclination of surface, and under similar circumstances of cultivation, can give on examination the same comparative result of rainfall and evaporation. If one district or unit of area

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be similar to the other in all respects but the surface inclination, that which has the greatest slope will, as a rule, give the largest per-centage of water available for storage, because of course there will be less time for the rain to be absorbed. Again, the degree of cultivation will materially affect the result when two areas, otherwise precisely similar in their physical conformation, come to be compared one with the other, it being evident that an open and well-drained soil will be more favourable to the retention of water falling upon it than compact and impervious land. In every case the physical features of a district will each and every one of them force itself on the attention, as influencing the conclusion to be arrived at. If any general rule can be applied, it may be said that the greater the slope of the valley, the more rapidly it will throw surface water off; the more denuded the surface is of soil of any kind, the less will the escape of rain-water be retarded; and the more compact the rocks composing the geological structure of a district, the better will the circumstances be for impounding water. The volcanic rocks and those of the granite order will be as favourable as any that could be desired; while, on the other hand, porous rocks, such as the sandstones, chalk, &c., are too absorbent to offer the desired conditions for storage. It is not here asserted that all the water absorbed by porous rocks is necessarily intercepted from passing away to contribute to storage supply; much of it may be lost by evaporation and absorption by vegetables, but a considerable portion will often be found to contribute in the form of springs, if the disposition of the strata be favourable.

As a further source of loss, evaporation from the ground as well as from the surface of the reservoir, must be taken into consideration. The circumstances attending the latter source of loss will be considered further on, as this does not affect the question of how much of the total rainfall may be made available.

The question how much water will be evaporated at any moment from the surface of land is one involved in considerable difficulty; and so many disturbing elements enter into the solution of the problem, that its accurate determination may be regarded as hardly possibly of attainment. The hygrometric state of the ground's surface, the aspect of the sky, the amount of wind, and the temperature, will all, in their degree, exercise a sensible influence on the amount of water that the ground will give off from its surface; so that, in fact, it is doubtful whether any reliable and philosophically correct conclusions can be arrived at. The resultant facts from such experiments as have been carefully conducted afford, after all, the only data for the engineer to arrive at any general conclusion by; and for forming

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a rough estimate for the probable available rainfall of a district, the following proportions of available actual rainfall may be accepted as furnishing general data; but they are not meant to obviate the necessity of a careful and specific examination of the circumstances likely to affect the design of any particular work:

Steep surfaces of granite, gneiss, and slate	100
Moorland and hill pasture	60 to 80
Flat cultivated country	40 to 50
Chalk	0 to 0

In order to arrive at more specific, and truly reliable results, the engineer will have to make a series of accurate observations on the discharge of the stream or streams that carry away the rainfall of a district; and by doing so, and at the same time comparing the result with the amount of rain registered by the gauges—which should also, of course, be kept with accuracy in the locality under examination—an approximately true estimate of the available rainfall will be arrived at.

If there is time in the preparation of a project to make the necessary examination of a district, it is evident that the results will speak for themselves; and there will be no necessity to enter into abstract speculations concerning the theory of the influences affecting loss by either evaporation or absorption.

In proportioning the size of a storage reservoir to the area of the catchment basin, the engineer will, of course, in the first instance be guided by the requirements of the work. The object of the undertaking may be any one of the following:

To husband a scanty rainfall.

To check the injurious effect upon the country by floods.

To add to the discharge of a stream, by preventing the escape of the flood waters.

The amount of storage will always be part of an engineer's data in designing works. It will either be his object to store the whole of the water that the drainage area will afford, which will be the case in impounding water for irrigation, for example; or a certain fixed demand, governed by the want of a town or other requirements, will determine the amount of the rainfall that it will be necessary to retain for supply. In England the demand for water supply may be reckoned at from 150 to 180 days, depending on the amount, and the constancy of the rainfall; as a rule, the six months' supply will be the safest to adopt. The following Table, extracted from Mr. Beardmore's work, shows the proportions that have been observed in designing some of the best constructed reservoirs:

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LOCALITY.	Height above Sea.	Drainage Area.	Total Discharge for the Year.	Discharge per Square Mile.	Representing Rainfall per Annum.	Registered Rainfall per Annum.	Reservoir Room, per Square Mile.	Proportion of Storage to available Rainfall.
	ft. ft.	sq. m.	c. ft. per m.	c. ft. per m.	in.	in.	c. ft. in mill.	
Bann Reservoirs, 1837-38	400 to 2800	5·15	1092·6	210·2	48·0	72·0	36·0	$\frac{1}{2}$
Greenock, 1827-28, flat moor ...	512 to 1000	7·88	1416·6	197·7	41·0	60·0	38·0	$\frac{1}{2}$
Bute, 1826	200 to 350	7·80	819·0	105·0	23·9	45·4		
Glencorse, Pentland Hills	724 to 1600	6·00	600·0	100·0	22·3	37·0	7·66	$\frac{1}{5}$
Belmont, 1843, moorland.....	850 to 1600	2·81	630·4	224·3	50·7	63·4	26·8	$\frac{1}{2}$
" 1844, "	...	...	412·8	146·4	33·8	50·0		
" 1845, "	...	...	511·2	181·9	41·2	55·0		
" 1846, "	...	...	411·3	146·3	33·2	49·8		
Rivington Pike, 1847	800 to 1545	16·25	2880·0	176·7	40·0	55·5	29·6	$\frac{1}{2}$
Longendale "	500 to 1800	...	...	...	49·5	55·5		
Swineshaw "	500 to 1800	...	...	...	37·0	49·3		
Turton and Entwistle, 1836.....	500 to 1300	3·18	576·7	181·3	41·0	46·2	31·43	$\frac{1}{4}$
" " 1837.....	...	...	548·2	172·3	39·0	48·2		
Bolton Waterworks	800 to 1600	·80	100·2	125·2	32·7	...	25·6	$\frac{1}{4}$
Ashton " 1844	800	·59	40·7	65·5	15·5	40·0	21·0	$\frac{1}{3}$

From this it appears that the proportion between the amount stored and the total rainfall varies between one-half and one-fourth.

The rule suggested by Professor Rankine "for estimating the available capacity required in a store reservoir, that founded upon taking into account the supply as well as the demand," is probably the best that can be adopted in designing waterworks for the supply of a town, "for example, 180 days of the excess of the daily demand above the least daily supply, as ascertained by gauging and computation in the manner above described." In order that a reservoir of the capacity "prescribed by the preceding rule may be efficient, it is essential that the least available annual rainfall of the gathering grounds should be sufficient to supply a year's demand for water." In calculating the capacity of a storage reservoir, the consideration of the surface evaporation must not be disregarded, especially when the works are designed for tropical or very dry climates. The amount of loss will in some cases be very considerable, for whatever depth of water be assumed to pass away into the air, it must be regarded as extending over the whole surface of the reservoir; or in fact, the cubic quantity will be equal to the product of the depth evaporated away and the mean surface area of the reservoir as the water rises or falls throughout the year. Some have gone the length of asserting that the amount of evaporation from the surface of large and deep bodies of water is probably nothing at all, or at any rate, not worthy of consideration; whilst others assume a much larger amount of loss than appears to be supported by

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observation. The following extract from the article "Physical Geography," published by the Society for Promoting Useful Knowledge, expresses intelligibly the conditions that tend to promote evaporation:

"Other things being equal, evaporation is the more abundant the greater the warmth of the air *above* that of the evaporating body, and least of all when their temperature is the same. Neither does much take place whenever the atmosphere is more than fifteen degrees colder than the surface upon which it acts. Winds powerfully promote evaporation, because they bring the air into continual as well as into closer and more violent contact with the surface acted upon, and also, in the case of liquids, increase, by the agitation which they occasion, the number of points of contact between the atmosphere and the liquid.

"In the temperate zone, with a mean temperature of 52¼°, the annual evaporation has been found to be between 36 in. and 37 in. At Cumana, on the coast of South America (N. lat. 10½), with a mean temperature of 81·86°, it was ascertained to be more than 100 in. in the course of the year; at Guadaloupe, in the West Indies, it has been observed to amount to 97 in. The degree of evaporation very much depends upon the difference between the quantity of vapour which the surrounding air is able to contain *when saturated* and the quantity which it actually contains. M. Humboldt found that in the torrid zone the quantity of vapour contained in the air is much nearer to the point of saturation than in the temperate zone. The evaporation within the tropics, and in hot weather in temperate zones, is on this account less than might have been supposed from the increase of temperature."

Thus it appears that evaporation, under highly favourable conditions, may take place to the extent of 9 ft. in depth—an allowance that will demand careful consideration in designing storage works. In India, where from the extreme dryness of the atmosphere the evaporation is found to be considerable, the usual allowance made by engineers for the evaporation from the surface of storage reservoirs is at the rate of half an inch of depth per diem for eight months in the year. Regarding the results that have been arrived at in Bombay, this allowance would appear to be about double what is necessary, for the observations extending over five years give a mean daily evaporation of less than a quarter of an inch. In Bombay, however, the atmosphere is much more humid than that experienced on the great table-land of the Deccan; and in Madras, where reservoirs are the speciality, it is probable that the actual loss is not far from being a mean between the two fractions. In Great Britain the mean daily evaporation is found to average less than the tenth of an inch.

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In estimating the quantity of storage water that will result from the drainage of any particular district, it will be essential to consider carefully the geological disposition of the strata characterising the locality in which it is contemplated to establish the works. This, although a matter that may influence the effectiveness of an undertaking to the extent of success or failure, will appear to the purely practical man to imply a degree of refinement that is uncalled for. There will be no difficulty however in showing that the geological conformation of a district may be such as, on the one hand, to materially contribute to the efficiency of a storage reservoir, or on the other to prove so defective that no engineering skill or pecuniary outlay could remedy it. A condition of geological structure perhaps the most favourable that could be imagined is that shown in Fig. 1. This diagram represents a geological section taken at right angles, or nearly so, to the axis of the valley that it is proposed to convert to the purpose of storage. This somewhat peculiar structure is what is geologically termed *synclinal*, the beds inclining away from the axis of the valley, and is the result of an upheaving force having taken place underneath the points of greatest elevation. Subsequent to the upheaval and consequent displacement of the strata, the process of denudation has taken place, cutting the upper beds, and leaving the outcrop exposed, not only inside the basin, but in the adjoining valleys at O and O. Now, it is evident that if the highest ridges bounding the valley be taken to mark the line of water-shed, and therefore limiting the area of the catchment basin, it is possible that the estimate of the amount of supply may be found far short of what the district will yield. A certain proportion of the rain falling upon the outcrop at the points O O will be absorbed by such of the strata as are porous, and the water, percolating through the bedding, till an impervious stratum is met with, will find its way down the course of the stratification, till it ultimately reaches the reservoir in the form of springs. and contributes more or less to the maintenance of the supply. The converse of this condition of things will be readily understood by reference to Fig. 2. It also represents a section taken directly across the valley of the proposed reservoir. Here the strata of the earth's crust incline against each other consequent upon some disturbing force having taken place to elevate them, and are said to be *anticlinal* to the axis of the valley. In order to account for the formation of a valley on the summit of the ridge, that at first was thrown up, it is to be understood that the upper beds suffered fracture in the process of upheaval, and subsequently were exposed to denudation. These valleys of elevation are evidently not to be desired as situations for the establishment of storage reservoirs. The area of the gathering

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grounds will be much more limited than the extent of the water-shed would appear to indicate; and cannot safely be relied upon to give an estimate of the quantity of water that the valley will afford. A certain amount of water will undoubtedly pass over the surface in times of heavy and continued rain, before it can be absorbed; but there is no doubt that of all the water absorbed by the ground, by far the greater portion will follow the inclination of the strata, and come out as springs in the adjoining valleys.

Fig. 3 shows a geological section that combines in it favourable and unfavourable conditions for the storage of water. On one side the outcrops of the strata are found to extend beyond the highest point of water-shed line, whilst on the other side the strata incline away, producing such a condition as would favour the escape from the valley of the water absorbed.

Certain rules are in general use for estimating the quantity of the total rainfall that will be lost by absorption and evaporation, with a view to determining the proper proportion to be observed between the reservoir and the area of the catchment basin. Two-thirds of the whole fall is sometimes taken to represent the loss that may be expected from the drainage of any district, in general terms—one-third being assumed as the amount that may actually be intercepted for utilisation. Some authors leave a much smaller margin, and state that fully two-thirds of the total rainfall may fairly be taken as available for storage. This is a large discrepancy when the application of the rules is taken to be general: but when the statements are applied to separate districts and different countries, there is nothing irreconcilable in them. General rules are undoubtedly of much value if they be received with qualification, and are not adopted as of absolutely universal application. They cannot however with safety be substituted for specific investigations, when so much depends on starting with accurate data.

Reservoir Sites.

The special requirements of each particular case will, as a general rule, go far towards determining the selection of a site for the establishment of storage works. Assuming however that there is a considerable extent of country situated advantageously in relative position to the locality at which it is proposed to utilise the water, and that there is a choice of ground, the point to be considered chiefly will be the natural lie of the country. To throw an embankment across a valley at any point without due regard to the configuration of the ground would most probably result in an expensive and ill-designed scheme;

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for under such circumstances the cost of the dam would bear a very large proportion to the quantity of water stored. It will rarely happen that, in the examination of the resources of any particular piece of country, some special features will not present themselves, favourable to the situation of storage works. The most advantageous disposition of the ground will be when two spurs of high land approach each other, forming a narrow outlet for the stream, and leaving a wide space above them in the valley for storage. Such a configuration is not uncommonly met with at the junction of two streams, as shown in Fig. 4. This is merely a sketch from memory, by the author, of a reservoir that he designed in India for purposes of irrigation; and it will be evident that the disposition of the ground was singularly favourable in every respect for the construction of a large storage work. The area of the reservoir, as designed, was about three square miles, and the maximum depth 90 ft., the area of the catchment basin being about 60 square miles. Such favourable situations for storage are of somewhat rare occurrence; for when the contour of the land is what is desirable, it may be that the area of water-shed is not adequate, or possibly the geological condition of the ground may be unfavourable, or the materials for the construction of a sound bank are not available. In examining large tracts of country in India, with a view to the establishment of irrigation reservoirs, the author found that more reliance was to be placed on a careful examination of the map in the first instance, than on the common plan of making personal explorations of the country. A good map will show at a glance, especially if the hill-shading has been carefully engraved, the points at which the supply will be found sufficient to justify the undertaking; and will probably furnish a pretty true indication of sites at which embankments may be advantageously constructed.

In tropical climates, where the rainfall is in places very scanty, and where the land is not of great value, it not unfrequently happens that such situations prove available for the establishment of large storage works as would not under any circumstances be made available in England. These sites are to be found, not at the head of a valley, but at some considerable distance down the course of a stream, where, the general inclination of the country being slight, a low embankment serves to store a very large area of water. The apparent disadvantages of such a site for storage are the large area of land swamped and lost to the cultivator and to Government, and the great surface exposed to evaporation under a tropical sun and the influence of a dry wind. In India, the first objection is one of comparatively little moment, considering that in those districts

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where irrigation is most required the value of land is very trifling. From 1s. to 2s. is about an average rent per acre, where land is under dry crops; but when water is available, the cultivators can, with profit, afford to pay 30s. per acre. It is therefore evident that, so far as Government is concerned, there is no sacrifice in the matter, but, on the contrary, an unspeakable benefit is conferred on those landowners who hold farms below the reservoir; and an ample supply of water is stored in the dryest seasons to mature those crops whose failure almost inevitably reduces the people to the verge of starvation. The evaporation from these lakes is, beyond question, a source of very considerable loss, and one that admits of no possible abatement. Estimated as above, at about half an inch vertical for eight months of the year, the loss frequently amounts to one-third of the whole body of water stored. As a set-off against this and other objections, the facilities for constructing these reservoirs of great extent, are considerable. In the first place, the embankments, being very low, are rapidly and cheaply constructed by native workmen; and when finished, the head of water even at the deepest point is not sufficient to try the work to any great extent. Further, the greater the extent of the reservoir, the less inconvenience is experienced from silting. The streams, owing to the suddenness of the rainfall, come down heavily charged with earth in suspension, the mass of which is deposited like a miniature delta at the influx of the reservoir, instead of passing on and resting near the embankment, as invariably occurs in reservoirs of small extent. The immense consumption of water necessary to confer any appreciable benefit by irrigation is of itself the strongest argument in favour of these broad and shallow reservoirs; for it is not possible to find in the upper part of a valley such sites as would store the requisite quantity of water without an embankment of excessive dimensions; and moreover, the catchment area in such situations is not usually sufficient to serve, with a scanty rainfall, for the supply of a very large reservoir. It is not, of course, maintained that this mode of storing water is by any means applicable in England, for the circumstances and requirements in each case are wholly dissimilar.

Supply.

The reservoir site being supposed everything that could be desired, as regards the disposition of the ground, the supply will next engage attention as a matter of course. Assuming that the gathering grounds are sufficiently extensive, it is presumed that the reservoir will be constructed to contain sufficient water

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to meet the maximum demand, whatever that may be calculated at; and in order to determine with accuracy what capacity the reservoir will have with different heights of embankment, it will be necessary to carry out certain levelling operations over the ground. The least elaborate manner of proceeding will be to run a series of cross-levels through the valley, referring all to the same datum, and by comparing these levels to ascertain what the average depth will be for a given height of bank. Having decided the height of the water-level, the next operation will be to contour round the basin, and to survey the boundary-line. In this way may be acquired sufficient knowledge as to the storage capacity, to justify the procedure with the work. When the execution of the project has been determined upon, it will be advisable to make a more accurate survey of the bed of the valley, and this can best be done by covering the whole plan with a series of contour lines at a vertical distance from each other of about 5 ft. This kind of survey will be of lasting value to the engineer, for it will enable him to calculate what quantity of water the reservoir will contain at each foot of depth; and, consequently, he will know, from a mere inspection of the gauge in the reservoir, how much water he has at his disposal for service.

It has been assumed that the gathering grounds are sufficient to maintain the requisite supply in the reservoir; but it may be well to pause and inquire what extent of water-shed will be sufficient to furnish a given supply, and what method may be adopted for supplementing an insufficient drainage area. It has before been remarked that the only reliable information, when there is any question as to the sufficiency of the rainfall or the area of the catchment basin, can be derived from careful gaugings of the stream or streams that may be depended upon to contribute to the supply. If the catchment area is very large as compared to the capacity of the reservoir, a mere inspection of the map and an exploration of the ground will generally be conclusive as to the sufficiency of the supply for storage. Should there not be such conclusive evidence on this point, it must be determined by measuring the quantity of water that absolutely flows off the ground, at the same time gauging the rainfall. This latter precaution would appear unnecessary, but in truth it is of great value, for it will furnish, by comparison with the rainfall registers that have been kept through the same year, and a series of previous years, evidence as to the amount of available rainfall that may be expected during terms of comparative drought. If the supply of a town with water be the desideratum, the rule to be rigidly observed is that of making a *minimum supply meet the maximum demand*, and therefore it is of the highest importance to determine,

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beyond any doubt, what the minimum yield of a catchment basin will be.

As a mode of supplementing an insufficiently large drainage area, catchment drains or feeders have frequently rendered good service. These are cuts that are carried outside the water-shed line to arrest the surface drainage and catch the contributions of small streams, and conduct the water into the reservoir. The greater the area enclosed between catchment drains and the water-shed line, the more valuable will they be as aids to the supply of the reservoir. They of course virtually extend the area of the catchment, adding so many square miles or acres to the rainfall.

Designing of Works.

Knowing the exact requirement of a given population, or rather having fixed, after every consideration, the daily consumption of every individual that it is proposed to supply, there will be no difficulty whatever in proportioning the reservoir to the demand upon it. It is sometimes necessary, however, to provide reservoirs for the purpose of preventing damage to the country by floods, and in this way the inconvenience and injury naturally consequent upon very sudden and excessive falls of rain may be to a great extent obviated. The duty of the reservoir will be to arrest all water in excess of what the stream can carry within its banks, and to dispose of this excess water, so to speak, in detail, after the excessive rainfall has become moderated. A comparison of a stream's discharge, taken at highest floods, with the quantity that it can carry without overflowing its banks will show the excess that has to be retained by the reservoir; and these data can only be arrived at through a carefully kept record of the extent of the floods and of their duration. The maximum flood in this consideration will not be that which rises to the greatest height for a short time, but will be the product of the excess above what the river can discharge by the length of time the flood lasts: which will, in fact, be the necessary capacity of the reservoir.

The Table given on page 231 will afford an interesting study when compared with the following Table, extracted in part from the same work. The first gives a comparative view of the volume of water gauged and stored in small hill districts, the last column indicating the proportion of the total available rainfall to the amount actually intercepted for storage. The following Table shows the ordinary summer discharge of various rivers, streams, and springs, as unaffected by immediate rain:

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RIVERS.	Height above Sea.	Drainage Area.	Total Discharge.	Discharge per Sq. Mile.	Representing Rainfall per Annum.	Total average Rainfall per Annum.
	Valley. Hill. ft. ft.	sq. miles.	c. ft. per min.	c. ft. per min.	in.	in.
Thames at Staines, chalk, greensand, Oxford clay, oolites, &c.	40 to 700	3086	40,000	12·98	2·93	24·5
Severn at Stonebench, silurian	400 to 2600	3900	33,111	8·49	1·98	
Loddon (February, 1850), greensand	110 to 700	221 8	3,000	13·53	3·01	25·4
Nene, at Peterborough, oolites, Oxford clay, and lias	10 to 600	620·0	5,000	8·45	1·88	23·1
Mimram, at Panshanger, chalk	200 to 500	50·0	1,200	2·4	5·5	26·6
Lee, at Lee Bridge, chalk (Rennie, April, 1796)	30 to 600	570·0	8,880	15·58	3·53	
Wandle, below Carshalton, chalk	70 to 350	41·0	1,800	43·9	9·93	24·0
Medway, dryest seasons (Rennie, 1787), clay	...	481·5	2,209	4·59	1·04	
Ditto, ordinary summer run (Rennie, 1787)	...	481·5	2,520	5·23	2·19	
Verulam, at Bushey Hall, chalk	150 to 500	120·8	1,800	14·9	3·37	
Gade, at Hunton Bridge, chalk	150 to 500	69·5	2,500	36·2	8·19	
Plym, at Sheepstor, granite	800 to 1500	7·6	500	71·4	15·10	45·0
Woodhead Tunnel, millstone grit	1000	...	139	...	...	46·0
Glencorse Burn	750 to 1600	6·0	130	21·6	4·9	37·4

Where the reservoir is designed to check the injurious effects of floods, the proportion of the storage to the rainfall will, in most cases, be much smaller than what would be necessary to provide for the better part of a whole year's fall of rain; for it is not probable that the maximum known flood can ever exceed the amount that it would be necessary to store for economic purposes.

Proportions of Bank.

The proper proportion to be given to an embankment for the support of water is a question that appears to admit of a good deal of difference of opinion, some designers taking one view, some another, of the proper theory that is to determine the dimensions of a bank. Some few, with whom the author cannot agree on this point, maintain that a bank ought to be designed with strict reference to its theoretical power of resisting hydrostatic pressure, or the effort of the water to displace it. Regarding the question in its abstract form, it will be evident that any structure intended to sustain the pressure of water may be supposed to fail in one of two ways—either, in the first place, by yielding to the horizontal pressure of the water and overturning, or by progressive motion, *i.e.* sliding on its base. In considering the first theory, that of resistance to overturning, the easiest method of examining the question will be to take a simple example of a vertical rectangular wall, and

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ascertain what power it exercises to resist the pressure of water. The pressure of water upon any plane surface immersed is known to be *equal to the area of that surface, multiplied by the depth of its centre of gravity below the level of the water and by the weight of a unit of water.* Generally speaking, the unit adopted in calculations is a foot; and the unit of water being taken at a cubic foot, weighing 62·5 lb., the resulting product from the multiplication of the three quantities will give the *pressure* in pounds on the surface immersed. Let it be supposed, for simplicity, that water to the depth of 10 ft. has to be sustained by a vertical rectangular wall, as in Fig. 5. It is usual to take but 1 ft. length of the wall for the calculation, though it will not affect the result whether one foot or one hundred feet be the length assumed. We then have the surface under pressure = 10 square feet, the depth of the centre of gravity = 5 ft., and the weight of a cubic foot = 62·5 lb., the product of which quantities gives us 3125 lb., the *pressure* on 1 ft. length of the wall. But this pressure is not the whole of the force that the wall has to resist; the leverage that it exerts must also be taken into account. In the example under consideration—viz. that of a vertical plane with one of its sides coinciding with the surface of the water, as in Fig. 5—the whole of the pressure is so distributed as to be equal to a single force acting at a point one-third of the depth from the bottom. Thus, the total force to be resisted by the wall is $3125 \times 3{\cdot}33 = 10{,}406$, which is the *moment* tending to overturn the wall.

It is evident that a certain weight of the wall must be opposed to this overturning force; and as the height of the wall and the length are determined quantities, the thickness alone remains for adjustment. But as a rectangular wall in upsetting is considered to turn upon a single point, F, in the Figure—viz. the outer line of the foot of the wall—there will be a certain amount of leverage to assist the wall in resisting the pressure of the water. This leverage is the horizontal distance of the centre of gravity of the wall from the turning point, F, and when the structure is rectangular and vertical, it is equal to half the thickness. *The amount of the wall's resistance will then be equal to the number of cubic feet in one foot of its length multiplied by the weight of a single cube foot of masonry and by half the thickness of the wall.* Taking w = weight of a cubic foot of water = 62·5 lb., w^1 = weight of a cubic foot of brickwork, say 112 lb., x = thickness of the wall, and h = the height, the conditions of simple stability will be fulfilled when

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$$w^1 \times h \times x \times \frac{x}{2} = w \times h \times \frac{h}{2} \times \frac{h}{3} \quad \ldots \quad \ldots \quad (1)$$

$$\frac{w^1 h x^2}{2} = \frac{w h^3}{6};$$

and solving for x, we get:

$$x = \sqrt{\frac{w h^2}{3 w^1}} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (2)$$

the thickness of the wall = 4 ft. 4 in.

A simple example has been selected for illustration; but of course a rectangular section of wall would not be found generally applicable in practice, nor would it be convenient to limit the dimensions of a retaining wall of whatever kind to the *minimum* that would sustain the pressure. If this principle of calculation be applied to ascertain the stability of a bank of earth with long slopes of 2½ or 3 to 1, it can easily be shown that in every case the resistance of the bank to overturning is greatly in excess of the horizontal leverage exercised by the water sustained.

The only theory, then, in any degree tenable is that assuming a bank in yielding to the pressure of water to slide on its base. In order to conceive how this can apply, it is necessary to assume the embankment to be a rigid body resting, for a given length of its section, on a horizontal plane; and without any adhesion, or a very small fraction, existing between the surfaces pressed. The amount of the friction, however, is just the point upon which the whole matter hinges, and until it has been ascertained that the surfaces of earth that are carefully incorporated with one another have any such thing as a co-efficient of friction, it is idle to pursue the investigation by a mathematical mode of reasoning. The conditions of stability will be satisfied when the horizontal component of the water's pressure against the bank will equal the weight of the bank, plus the vertical pressure exercised by the water to hold it down and multiplied by the co-efficient of friction; but nothing is known of this co-efficient, and consequently the equation remains incapable of solution. As a matter of fact, embankments do not slide bodily forward on their base when they fail, but give way from other causes than mathematical reasoning can supply. Landslips, it is true, to some extent support the principle that maintains the sliding of embankments; but, here, the circumstances are widely different. Landslips either take place when a mass of earth rests upon an *inclined* surface of rock, with an ample supply of water to lubricate the surfaces in contact, or else they are the result of cutting or embanking earth to a higher slope than the material will stand at: the infiltration of water also in this case

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is the chief agent in producing the effect, acting as a lubricant, and causing the earth to assume its natural slope. In each case the surface of separation is an *inclined* plane, an element that does not enter into the question of the stability of embankments, by either of the modes of reasoning above referred to. The principles that direct the design of embankments to retain water are not those that apply to the calculation of the forces to be resisted or the means to overcome them, any more than breakwaters and harbour walls can be designed on mathematical principles. The whole question naturally turns on what slope the material composing the bank will stand at. If earth could be got to remain at a slope of 1 to 1, even though the embankment had no thickness whatever at top, it would be amply sufficient in weight to uphold the water in a reservoir. This, however, cannot be accomplished without the assistance of retaining walls, which would be found in most cases much more expensive than the additional earth required to increase the slope to the angle of stability; and therefore the section is so disposed that the earth shall stand both inside and outside the reservoir at such a slope as will be under all circumstances permanent. These slopes have been determined by long practice and by success and failure in pre-existing instances—that is to say, the limits have been laid down, for it is not to be assumed that all descriptions of earth will fall to exactly the same slope when exposed to the constant action of water or weather. Earth when subjected to the contact of water almost invariably loses a certain amount of its stability, and therefore it is usual to give the inner side of an embankment a longer slope than the outside. In most of the best existing examples the inside slope of the bank is either 3 to 1 or 2½ to 1, and it is rare to meet any departure from this rule. The outside slope may be designed at from 2 to 1 to 3 to 1, depending upon the character of the material, its power of withstanding the erosive action of the air, and the means used to protect the surface from being washed off or from crumbling away. In designing embankments, the impermeability of the earth is a matter that cannot be relied upon. There are, it is true, innumerable embankments now standing that have never allowed the escape of a drop of water from the reservoir, although no special precaution was taken to make them watertight. Of these India abounds with examples, the introduction of a puddle-wall being in the older embankments of very exceptional occurrence. The earth was merely dug out close at hand, and carried by the workpeople in baskets on their heads to where it was deposited, without any regard to the mode of disposing the material. The author has had occasion to construct a considerable length of *levée*, or embankment, on this

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simple plan for the protection of the country from the flooding of a river; and although, so far as he is aware, no flood has yet taken place to test the work, he has, from the study of existing examples, entire confidence in the result. The earth, so far as practicable, was disposed in layers, and before each was completed it was thoroughly consolidated by the tread of the workmen. It is not suggested that the puddle-wall should be dispensed with in designing embankments, for the additional degree of safety, in most instances, will more than compensate for the extra expense it entails; but, in low embankments made of good retentive clay, the precaution of puddling is by no means a necessity.

In most of the best examples of embankments in England, the practice adopted has been to carry up the earthwork in layers of 2 or 3 ft. in thickness, disposed in the manner shown in Figs. 6 and 7, and at the same time to construct in the centre of the bank a wall of well puddled clay, the foundation of which is carried down for whatever depth may be necessary in order to reach an impermeable bed of earth or rock. It is not in all situations possible to procure earth exactly suitable and in sufficient quantity for the construction of an embankment, and consequently, it is usual and advisable to dispose the best part of the material—that is, the most retentive of water—in juxtaposition to the puddle wall, as indicated in Fig. 6. In this example the selected material is disposed equally at either side of the puddle; but, as its function is to withstand the admission of water, it would probably be more consistent, though less in accordance with practice, to place all the selected material on the inner side. The practice of excavating the earth for an embankment from the inside of the reservoir is one that should not be followed without caution. Removing so large a mass of material would, no doubt, give a considerable increase of storage room; but sometimes the bed of a reservoir is covered by a layer of impervious clay that is of immense value, and if this be cut through or removed, it is quite possible that a bed of porous material may be met with sufficient to allow the escape of water when it comes to be admitted. In specifying for the dimensions of the puddle wall, a sound rule for adoption is, that it shall have a thickness of 10 ft. at the top water-line and increase in thickness to the surface of the ground at the rate of 1 in. on each side for every foot of height. Before any excavation is commenced, it will be essential to make a sufficient number of borings to ascertain the nature of the soil beneath the surface.

It may here be mentioned that professional men are not apparently yet agreed as to the principles to be kept in view in constructing reservoir embankments; and this want of concurrence

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never was more apparent than in the discussion that followed the destruction of the Dale Dyke reservoir, near Sheffield. Fig. 8 shows a cross section of this ill-fated embankment, and Fig. 9 a plan of the embankment site after the catastrophe. The bank was 95 ft. high, with slopes of 2½ to 1, and a top width of 12 ft. The puddle wall was 16 ft. in width at the ground-line, and tapered to 4 ft. at the top of the bank. This embankment, with the exception of the puddle wall, was composed of rubble stone and shale; an additional price having been given by the engineers to ensure the use of the former material; which proves, at any rate, that this mode of construction was adopted on principle and not through ignorance or mistake. From the evidence given by the engineers of the company, it appears that it was, in their opinion, desirable that the inner part of the embankment should be permeable to water, because earth was much more likely to subside and slip than an open and less yielding material like stone. This mode of construction implies that the puddle shall be fully sufficient of itself to resist the passage of water, and that there is no necessity to relieve it of any part of the pressure against it. Of course if a bank be composed of open work, every point in the face of the puddle is exposed to the full and direct hydrostatic pressure; and if at any point there is the smallest fissure or imperfection, the water has full power against it, and will, to a certainty, take advantage of such point to breach the dam. The assumption, then, of the constructors of this and the Agden reservoir evidently was that a puddle wall of some 25,000 square feet of area was to be constructed without an imperfection of any kind, or a single weak point in the whole surface.

The obvious reason for employing puddle at all in embankments is to thoroughly close up any imperfection that may occur in the earthwork; it is in fact merely an accessory, and cannot be relied upon of itself to secure the embankment against destruction. If an embankment be constructed of good sound earthwork, properly executed, it is highly probable that the water may never penetrate half way through to the puddle wall, and probably, in the majority of examples, has not done so. Earthwork, however, is not always executed without imperfection; some decomposable material may be introduced, which in course of time dissolves, leaving a fissure; one part may be at first less consolidated than another, and, subsiding, lead to imperfection; or an embankment, be it ever so well constructed, may be burrowed through by moles, rats, and other vermin. It is to meet the first two of these sources of imperfection that puddle is used; and if, by such fissures as may occur in ordinary earthwork, water is admitted as far as the puddle wall, it can only exercise pressure against it at a few points, the puddle and

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earth being, in good work, so bonded and incorporated with each other that there is no space left for the water to occupy and press against the surface. Most who have read the account of the disaster that occurred in March, 1864, at Sheffield, will recollect how singularly conflicting the professional evidence on that occasion was. Some of our first engineers were ranged against each other in order to satisfy the public as to whether the failure of the embankment was attributable to bad engineering or to a landslip; and although the impression finally remained on the public mind that "there was not that engineering skill and attention to the construction of the works that their magnitude and importance demanded," the engineers were fairly divided in opinion as to the cause of the disaster. One section pronounced, without qualification, that the embankment gave way in consequence of a landslip, and entirely ignored the fact of the embankment being defectively constructed; whilst the other gentlemen gave their verdict dead against the company, and their mode of constructing water-tight banks. The two diagrams, Nos. 6 and 7, may be taken as indicating the system of constructing embankments most generally approved of. The puddle, as will be observed, is carried up to the natural surface of the ground without any batter, and from that point slopes on each side to the top of the bank; on either side of the puddle is disposed, in concave layers, the most sound and retentive part of the material, and outside of all comes the oridnary earthwork.

As a security against the eroding action of the water, and also against the inroads of vermin, the most desirable, as well as the most usual practice is to pitch the whole of the inner face of an embankment with stone, carefully laid by hand. Neglect of this precaution has led to the destruction of many embankments in other respects securely constructed, and even when ample height of bank above the surface of highest water was provided. In all ordinarily inclement weather the disturbance of the surface of a reservoir amounts to no more than a mere ripple; but when the surface is of large extent, and a severe storm blowing, the waves produced are such as to cause reasonable apprehension, and in fact, have, before now, overtopped the bank and cut it down, till the water flowed over and caused the destruction of the work. In most cases, it will be necessary to leave about 5 ft. between the level of the highest water and the top of the embankment, and never less than 3 ft.

A mode of construction not very generally used, but apparently consistent with reason, is that shown in Fig. 7, the embankment for the Bideford Waterworks. It consists in covering the whole of the inner face with a layer of puddle, with sometimes a layer of peat outside it. On some occasions it has been

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thought desirable to mix with the puddle a quantity of small stones or furnace cinders, by way of obstruction to vermin—a precaution that is by no means unnecessary. As an instance in point, the author is reminded of a masonry dam in India that had to be pointed every year regularly, because the fresh-water crabs in the reservoir found it convenient and promotive of their development of shell to appropriate the mortar to their personal use. The joints were cleaned out as effectually at the end of each monsoon as if the work had been done to order.

The preparation of the foundation for an embankment is a matter requiring some care. The soil, consisting of grass, roots, &c., and other matters of a decomposable nature, should be carefully removed over the whole surface to be covered by the bank; and if any porous material, such as sand or gravel, be present, it must be removed, until a compact and water-tight bed is arrived at. The bank must, in fact, be in contact with some sound and reliable material that will not admit the passage of water.

Appendages of Reservoirs.

Under this heading may be considered:

The whole apparatus for allowing the water to escape, including the pipes, the valve tower, and the culvert;

The waste sluices;

The waste weir or by-wash.

The most economical mode of discharging water from a reservoir is through a single pipe passing either through the embankment or immediately under it; but this plan cannot, under any circumstances, be recommended, though it is sometimes found in existing examples. It is open to several grave objections, the principal of which, perhaps, is that the failure of a joint under the embankment from unequal pressure, or from whatever cause, will probably produce the destruction of the embankment, or at any rate, entail a serious interruption to the supply, by the reservoir having to be emptied in order to repair the pipe. Buried in or under an embankment, a pipe is completely out of reach and out of view, and may be in a very defective state without its being possible to detect the imperfection.

In order to secure the satisfactory working of a reservoir as a source of constant supply, it is essential that the outlet pipes, valves, and all other appendages for controlling and regulating the escape of the water should be accessible for inspection and repair. The usual mode of accomplishing this is to carry the pipes out through a culvert of brick or masonry of sufficient dimensions to admit a man. This culvert communicates with the valve

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tower, as shown in Figs. 6 and 7, so that there is a complete communication between the outside of the reservoir and the inside. When unavoidable, the culvert is carried straight under the embankment in the natural ground; but the safest and most generally approved mode of construction is to bring the culvert round the end of the embankment, where it will be out of reach of injury from unequal settlement; a source of no small apprehension when either culvert or pipes alone are carried under the bank. Where possible, it is an excellent plan to run a heading through the solid ground, lining it with brickwork and puddling it, forming a tunnel entirely independent of the embankment. The principal objection to carrying either the culvert or pipes through or under the bank is their liability to fracture from the unequal settlement of the earthwork. It would appear that their liability to damage cannot with certainty be ensured by any reasonable depth of excavation, and is, therefore, generally disapproved of by the best authorities.

In the best constructions the culvert is situated half way or two-thirds up the embankment, and in such case the outlet pipes for drawing off the water in the reservoir act as syphons when the water surface has fallen below the culvert. Fig. 6 shows a plan, as well as a cross section, of a reservoir dam designed for general application by Mr. Rawlinson. Here the bottom of the culvert is about 25 ft. above where the inner slope of the embankment intersects the ground at the lowest point. The syphon pipe is also shown passing through the culvert; the horizontal culvert is connected with a shaft inside the embankment, in which are placed the valves for leading off the supply from the reservoir. The valves are made to be closed on the inside by valve spindles and screws, and the inlet pipes are closed on the outside by plugs which can be applied from the top of the valve-tower. Thus the engineer has full command of the whole of the outlet works; all the pipes and valves are easily accessible and under perfect control, so that the supply can at any time be arrested for the repair of any derangement that may occur, even to the removal and replacement of all the pipes. The inlet pipes are shown in this example, as well as in Fig. 7, fixed at different heights in the valve-tower, the object of which is to draw the supply from the reservoir from points near the surface. Fig. 10 shows an arrangement by which this object is effected very simply. The outlet pipe, passing through or under the embankment, is connected on the inside of the reservoir by a flexible joint with another pipe of the same diameter, to the upper end of which is attached a float. This pipe is movable in a vertical plane, being controlled from lateral motion by the guide-posts, as shown. Such an arrangement admits of the water being drawn off from

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the surface, where it is least liable to be contaminated with impurities. Whatever arrangement be selected for drawing the supply off from a reservoir, the system of carrying the pipes, either with or without a culvert, through or under the embankment cannot be sufficiently deprecated; they are, in such a position, beyond the reach of inspection, and moreover, are very likely to induce leakage from the reservoir. It is usual to puddle carefully the culvert or pipes when carried under or through the bank, but, even with such a precaution, the water has under a considerable head a tendency to creep along the pipe, and, by soaking into the earthwork, may cause any one of the many evils that imperil and destroy embankments.

When embankments are not of great height, an exceedingly cheap and simple mode might be adopted for drawing off the water. This would be by laying a syphon over the embankment, as was done in the case of the middle-level drainage in Cambridgeshire, which syphon would at the inner side have a flexible connexion with another tube having a float attached, as above described. Such an arrangement would apply in *principle* to heights not exceeding 30 ft., as the pressure of the atmosphere would maintain no greater height. In practice however the syphons cannot be worked with success at much above 20 ft., for it is found that after a short time, the flow becomes arrested by the collection of air in the upper part of the syphon, and it becomes necessary to pump the air out constantly, to prevent it from interfering with the flow, as it would do if not removed. It would appear a simple matter, where it is desirable to adopt a syphon, to utilise the power of the water flowing out for the purpose of getting rid of the air; it might easily be applied, through a small wheel and suitable gearing, to work an air-pump fixed at the highest point of the syphon, making the whole arrangement self-acting. The arrangement could be successfully applied to irrigation tanks in India, where the embankments are frequently less than 30 ft. Each leg of the syphon should be provided with a valve to retain the water, and when the supply was intermittent it would be essential to have an opening at the highest point of the syphon, and some appliance, perhaps an air-pump, for filling it with water in case of leakage.

To ensure a constant discharge from a reservoir with a constantly varying head, several methods have been adopted; of these, one of the most ingenious is that used at the Gorbals Waterworks, near Glasgow. Fig. 11 represents a transverse section through the regulator-house, showing the arrangement by which the discharge is equalised. To the orifice of the outlet pipe, O, is fitted a square-hinged flap valve of wood, against which presses, by a friction roller, a lever, B, the arms of which

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are bent. To the upper arm is attached a chain that passes over a pulley, and is connected with a cast-iron cylinder or float, D, that stands in the reservoir, E, of slightly larger diameter. At the side of the entrance-door of the building is placed another cistern, G, of cast iron, closed at top, and communicating by a pipe, R R, with the vertical pipe, H, which is in connexion with the outlet pipe, and passes up the slope of the embankment, to carry away any air that may accumulate in the main. The cistern, G, is connected with the reservoir, E, by a pipe, K, which supplies water to float the cylinder, D. Now, it is evident that the discharge from the reservoir will be regulated by the position of the lever, B, and this again will be controlled by the height of the float, D. To regulate this height the supply from the cistern, G, must be self-adjusting, or be regulated by the amount of water flowing away. The float, N, has attached to it a spindle, on which are fixed two double-beat valves that work in the vertical part of the pipe, K, one of which admits water from the cistern, G, into the cylinder, E, and the other allows the water to escape from the reservoir, E. Now, if the surface of the water upon which the float, N, rests should rise above the proper level, the float forces up the spindle, closing the supply valve from the cistern, and at the same time opening the lower valve. Thus the supply is cut off and the escape opened, enabling the float, D, to fall. The subsidence of the float closes more or less the flap valve, and checks the discharge, in consequence of which the surface of the water falls, and with it the float, N, which consequently opens the supply valve, and again admits water into the cistern, E. Thus an almost perfect equality between the consumption and the supply of water is preserved. It would appear that the same effect could be produced by connecting the lever directly with a float on the surface of the water, but such an arrangement would only apply when the pressure against the flap is trifling.

It is essential that every reservoir should be provided with some means of getting rid of the excess of water that flows into it, and whether this provision be made by a waste weir, sluices, or waste pit, it is one that should not be omitted. The most advantageous position for a waste weir will generally be at some point remote from, and entirely unconnected with, the embankment, and occasionally a natural depression in the ground, as shown in Fig. 4, will afford remarkable facilities for the construction of an escape. The level of the crest of the waste weir with reference to the top of the dam will require to be carefully adjusted, the minimum difference of level being 3 ft., and the maximum about 10 ft., depending on varying circumstances,

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The height of the waste weir will, of course, regulate the top water level in the reservoir; and this must be fixed with regard to the probability of the embankment being overtopped by waves. The circumstances influencing the height of the waves in a reservoir are the extent of the water surface, the depth, and the amount of exposure to or shelter from wind, all of which will vary with each particular case. Under ordinary circumstances, the height of the top of the embankment above the crest of the waste weir should be for

an embankment	25 ft.	deep,	4 ft.
„	50 ft.	„	5 ft.
„	75 ft.	„	6 ft.

and for greater height of embankment the difference of level may be proportionately increased.

When the configuration of the ground does not afford any facilities for the construction of a waste weir after the manner described, sufficient provision for the escape of the overflow is made through a waste pit, as shown in Fig. 12—section of the Doe-park reservoir embankment. This waste pit, or tower, is generally a circular structure built over the outlet culvert inside the reservoir, and serves equally for access to the valves and for the escape of the flood water. With regard to the capacity of the waste weir or waste pit, whichever be adopted, it will be necessary to make ample provision for the discharge of the sudden accessions of flood water that reservoirs are subject to, and which so seriously imperil their safety. To provide for this there is an empirical rule amongst engineers that is supposed to suffice for the most urgent contingencies. It states that there shall not be less than 3 ft. of length of overfall for every hundred acres of gathering ground, but it is obvious that to proportion the length of the waste weir to a given area of country in all cases would be unreasonable.

The discharge over the weir will not depend only upon the quantity of rain falling on a certain area of ground, but also on the extent of the reservoir as compared to the gathering ground, and on the flat or precipitous character of the basin. The only safe mode, then, of proportioning the length of the escape will be to ascertain with exactness what the discharge of the stream or streams flowing out of the reservoir was during the greatest known flood, and then fixing upon an arbitrary depth for the water to flow over the weir, say 2 ft. or 3 ft., to calculate what length of overfall will suffice for the discharge of the excess water. In India, where large waste-weir accommodation is essentially necessary, while it is equally a necessity to save every gallon of water that is possible, it is a common practice to form

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a temporary dam, of earth and sods, on the top of the waste weir; this serves to pond up some 3 ft. or 4 ft. of water over the whole surface of the reservoir, and does not imperil the security of the works. In times of heavy floods the water rises and overtops the temporary dam, and no sooner does so, than the whole is carried away, and the water in the reservoir quickly subsides.

In works designed for the supply of towns, it is sometimes necessary to make provision to arrest the entrance of flood-water into the reservoir, as the streams may come down charged with large quantities of matter in suspension that would injure the purity of the water for domestic consumption. These streams may be diverted and carried round the margin of the tank past the dam, and can be admitted into the channel of the stream, or be utilised for mill power. On the Manchester Waterworks are constructed across the mountain streams weirs of an ingenious design, for the purpose of separating the flood-waters from the ordinary flow. Fig. 13 is a transverse section through one of these, showing the way in which the weir acts when the stream is at flood. The dimensions are adjusted from observations of each particular stream, so that the discharge up to a certain amount will take place into the channel for the supply of the town; but when the discharge increases, and the water becomes turbid, it has sufficient velocity to carry it over the opening, as shown in the diagram, and flows down to the compensation reservoir for the supply of mill power.

In determining the dimensions of a weir of this kind, it is first to be ascertained what the mean velocity of the water flowing over will be for a given depth of water, h, above the crest. The mean velocity, v, will be

$$v=\frac{2}{3}\times 8{\cdot}024\sqrt{h}=5{\cdot}35\sqrt{h}.$$

If the vertical height of the crest of the weir above the point to be overleaped by the cascade be called x, the distance across will be:

$$y=\frac{2v\sqrt{x}}{\sqrt{2g}}=\frac{4}{3}\sqrt{xh}$$

Before concluding, it will be well to give a brief consideration to the causes tending to the failure of embankments. The foregoing remarks will, in suggesting the best mode of construction, have anticipated much that might be said on the subject of failures; but there are a few points, the recapitulation of which the importance of the subject demands.

There are unfortunately on record accidents, if they can be so

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called, from the bursting of embankments, that if estimated by the loss of life attending them, are as appalling as anything within the memory of man. Thousands of human lives have been sacrificed to ignorance and false economy, as well as in some instances to natural defects that it would have been difficult to foresee.

The existence of springs on the site of an embankment is an undoubted cause for apprehension, and considerable care should be taken to carry all water from this source away, that it may not, as it certainly will if not checked, force its way between the surface of the ground and the seat of the embankment. In doing so there is every probability that the earth of the embankment will be washed out by constant trickling till a fissure is formed of sufficient dimensions to render the destruction of the bank a certainty, if the water from the reservoir should ever penetrate so far. As a provision against this source of injury, all springs found on the site of an embankment should be taken up and carried away in proper drains, sufficiently and securely puddled. Thus the water is confined to a single channel, and has no tendency to soak into the earthwork and blow it up in endeavouring to escape. In embankments of all kinds the presence of water is a most serious evil, and one by which may be accounted for some of the most extensive landslips that are on record. It is erroneous to assume that when water is the active element in producing disruption in an embankment or mass of earth of any kind, that it only acts as a lubricant between the surfaces in contact. The truth is, the bulk of earth is sensibly affected by the amount of moisture in it, as is seen in the subsidence of newly formed railway banks when exposed to rain. If then a sufficient quantity of water find its way into the centre of a bank that has been put together in a comparatively dry state, it will rise and soak into the earth until at length what was a solid mass becomes semi-fluid, settles into a smaller space than it before occupied, and as a consequence will leave a vacuity above it. The inevitable result is the subsidence of the superincumbent earth; but instead of resting, as at first on a resisting material, it floats, so to speak, on the semi-fluid mass underneath, and having little or no friction to overcome, slips away to a lower angle than it before stood at. Natural springs therefore, whenever they occur, must be dealt with carefully and completely. Exactly similar effects to those produced by natural springs may result from the defective practice of carrying outlet pipes through or immediately under embankments. Be the pipes ever so well puddled, there will be a tendency to trickling along the line of their direction, and assuredly if this trickle makes its way to the centre of the bank it will carry mischief with it. It is true that

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springs are occasionally found issuing from the foot of an embankment, without after several years causing any appearances to justify apprehension. The Doe-park reservoir is an example in point, and though at one time fears for its safety were entertained, the embankment is still standing, and, so far as the author is aware, the spring is still trickling away. An engineer of eminence was called upon to report upon the state of the works, and gave his opinion that, as the spring came away without any earth in suspension, there was no mischief taking place, and that the work was in a safe condition. There is no doubt that embankments in this condition require to be narrowly watched, although the presumption may be that, having lasted for several years, they will continue in safety.

The empirical and unscientific mode of proportioning the length of waste weirs has proved before now a source of danger and destruction to embankments, from the space afforded not being sufficient to discharge the excess water without the surface rising to such a height as to top the embankment. To avoid risk, the stream must be gauged with great care, and the discharge calculated for the greatest known flood; and if with a given head the length of the weir be adjusted to discharge this amount, or a little in excess, there will be no risk to the embankment.

Regarding finally the whole subject, the danger that may result from careless or unscientific construction, the large outlay entailed in the establishment of storage works, and the benefit that may accrue from them whatever their purpose may be, the subject cannot be undertaken on merely rational grounds. Its successful application will rest alone on the study of the question in its scientific details, and an ample practical experience.

DISCUSSION.

Mr. H. P. Stephenson said he entirely agreed with the author as to the impropriety of carrying a pipe through the embankment of a reservoir. He would extend his objection to the passing of a culvert through the embankment. If the culvert were laid on the natural ground, they would avoid the risks pointed out by the author, either of the settlement from the joints of the pipe, or of the water creeping along between the material and the pipe. He believed that the true principle of construction for reservoirs was the placing of a good puddle dam in the centre, and on each side of this dam layers of earth well punned in. One reason why he should prefer the puddle wall in the centre was that there was less tendency in the puddle to slip in such a position than when laid on the slope.

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Mr. ALBERT LATHAM agreed with Mr. Stephenson in his remarks as to the pipes and culverts; but he thought it was an open question whether the puddle wall should be in the centre of the dam. He had a strong opinion that it should be on the face of the dam.

Mr. CARGILL said that he believed that the reason the puddle wall was not required in Indian embankments, referred to by the author of the paper, was that the earth seemed to have been thoroughly consolidated by the continual trample of people upon it. That thorough consolidation was the great point in all puddling, and it was on that account that specifications were generally so stringent as to the thickness of the layers of the puddle. As to the position of the puddle wall, he could not see the particular value of having it in the middle of the dam, and he thought that a far better place for it would be the face, because the object of the puddle wall was to prevent the infiltration or the escape of the water. This could be effected by puddling the whole slope right down to the permanent strata. The puddle wall was not required to promote the stability of the dam. The question of putting pipes or culverts under the dam required more consideration. It was alleged that the putting of a naked pipe through the dam of the Bradfield reservoir was one of the causes of its bursting. In some very large waterworks now being constructed in Dublin there were two distinct sets of main pipes, and they were laid in two large culverts at the bottom of the dam. The culverts were large enough for a man to walk upright in them. If the foundation were well looked after, there would be no fear of the arch or dome of the culvert giving way in consequence of any inequality of pressure above it, as, if properly constructed, an arch would stand any amount of pressure short of what would crush the material.

Mr. BALDWIN LATHAM said he could not agree with Mr. Jacob that a dam could not be constructed from theoretical deductions; for unless regard was paid to theoretical considerations there might result either a deficiency of strength or a waste of material and labour. In the dam shown in the drawings, and designed by himself, the pipe did not run through, but on the outside of the dam, on the solid ground. It was a well received opinion among engineers that if you had a pipe or culvert running through an embankment, that pipe or culvert would be unsafe. He believed that well made and properly tested pipes were quite as safe as culverts when in the solid ground. A pipe was simply a small culvert made of iron instead of brickwork. In cases in which there was a tendency for the water to creep along the outside of the pipe, that might be stopped by having projecting flanges on the pipe. The same creeping of water

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might take place along a culvert as along a pipe. With regard to the slope of a dam, the inside slope should be greater than the outside slope, because the greater would be the stability of the dam, and the water would have less destructive effect on the dam: he had effectually prevented leakage by the use of socket-pipes. The square projection of the sockets was always presented to the reservoir, and the pipes were laid in the virgin ground. It was very bad practice to lay the pipes in made ground, and especially through a dam. Pipes laid under a dam should be tested under pressure after being laid and before being covered up, so that any defective joint might be discovered. In cases in which he had laid pipes through dams, they had been so tested, which resulted in good and effective work; but he was bound to say that, if the pipes had not been tested *in situ*, that the result would not have been satisfactory.

Mr. SCHÖNHEYDER said that Mr. Jacob had said that wherever springs occurred they should be well carried away. He (Mr. Shönheyder) wished to know how a spring was to be prevented from diffusing through the earth.

Mr. HENDRY said that he had seen pipes which were laid through embankments, but had never seen one that was perfectly tight. It was almost impracticable to make it so, owing to the continuity of the puddle being disturbed at the point where the pipe passes through.

The CHAIRMAN asked what was the largest diameter of pipe Mr. Hendry had seen used?

Mr. HENDRY replied that the largest was 18 inches. He had heard of several methods being tried, but he did not think it was possible to prevent leaking, more or less, from the reservoir along the outside of the pipe. He should like to be informed how it was possible to connect the puddle with the pipe; if the pipes be laid in the natural ground below the foundation of the embankment, then there is no fear of leakage, provided the pipes are properly laid.

Mr. JACOB, in replying to the discussion, said, that in the opinions that had been expressed there were but few points of disagreement with those that he himself held. He could not agree with Mr. Latham in his belief that embankments could be calculated on mathematical principles. In order to deal with embankments theoretically, they must be regarded as rigid masses, and be assumed to rest upon a horizontal plane. It could be shown mathematically that a rigid body of the same specific gravity as ordinary earth need not present the same section as is usually given to embankments, in order adequately to resist the pressure of water. A right-angle prism with the hypothenuse

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resting upon the plane would be quite sufficient to resist the pressure of water, even supposing the surface of the water to coincide with the upper edge of the prism. The reason of giving long slopes to an embankment is discoverable from the fact that banks, when exposed to the action of water, are found to waste and slip away to such an angle as will withstand the action of the water. The chief reason of the failure of embankments is the infiltration or soaking of the water from the inner side, which renders the material semi-fluid and causes it to subside into a smaller space than it originally occupied. The superincumbent mass then sinks and allows the water to overtop the embankment. The earth used for making embankments in the Deccan and in parts of the Madras Presidency in India is of a most suitable quality for the purpose. It is what is called "black soil," being very dark in colour, and of a highly argillaceous character. The colour is no doubt due to the presence of carbon. The clay makes most excellent puddle; but no doubt the consolidation produced by the tread of the workpeople is the real secret of the earth resisting the pressure of water so successfully as it does. In North America, the *levées* for protecting the country from flooding by the Mississippi are sometimes constructed simply of sand; and are found, for the most part, sufficient for their purpose. As regards carrying away springs from the seat of an embankment, there is no difficulty in ascertaining where they exist when the ground is laid bare, as they are generally well defined streams. Before the earthwork is commenced it is necessary to construct drains of masonry, or brickwork, or to lay iron piping to carry away the water clear of the work.

The CHAIRMAN said that the paper of Mr. Jacob was a very interesting one, and the subject was one which, during the last year or two, or, he might say, within the last week or two, had commanded the attention of the whole body of engineers. Last session a special Act of Parliament was passed that all reservoirs and embankments should be constructed to the approval of the Board of Trade. The subject of irrigation in India, which was alluded to in the paper, was one of vital importance. There was no question that the only means we had of irrigating that country in an efficient manner was by the construction of reservoirs.

THE END.

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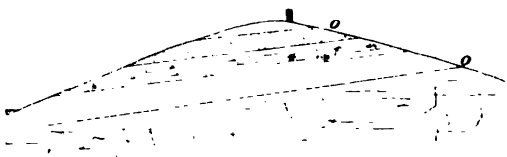

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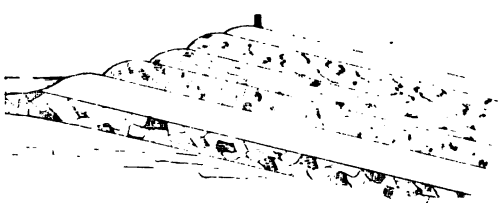

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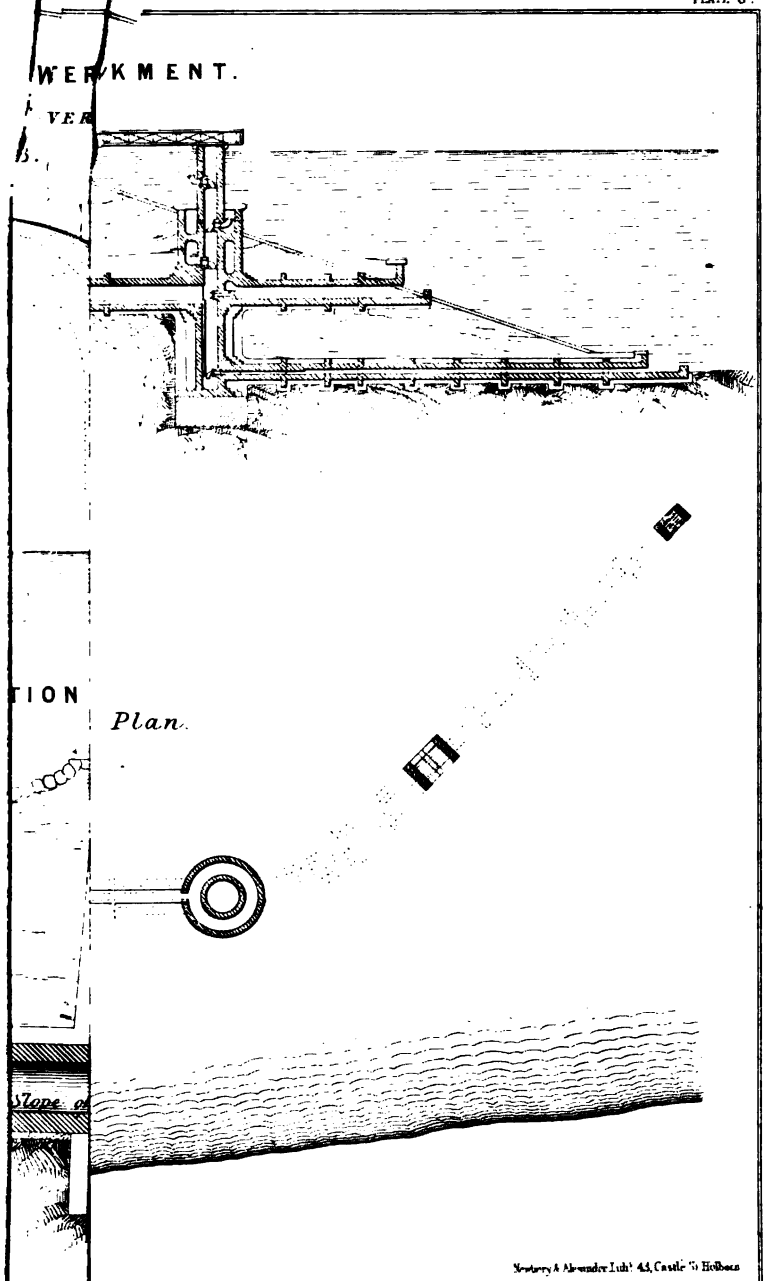

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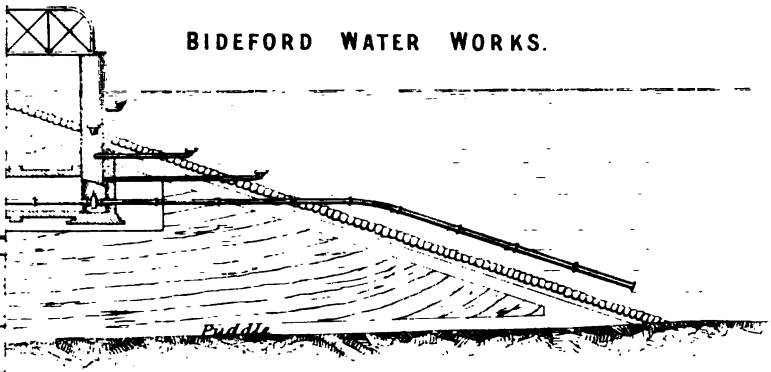
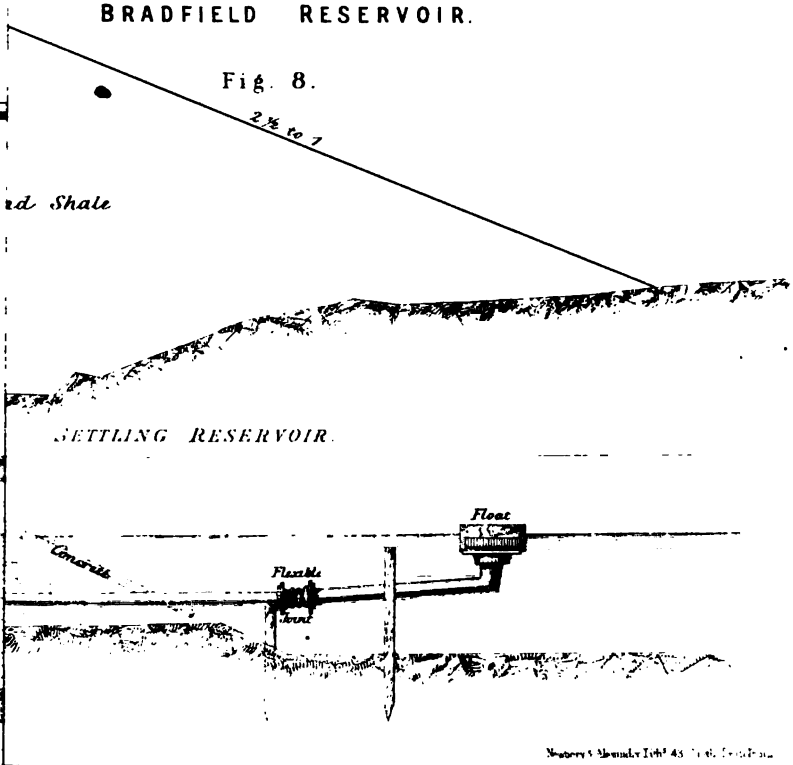
BIDEFORD WATER WORKS.



BRADFIELD RESERVOIR.

Fig. 8.



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